ENGINEERING EMPOWERS GROWERS TO IMPROVE IRRIGATION MANAGEMENT

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ABSTRACT

Research and extension personnel in the established irrigation regions of south east Queensland have traditionally promoted improved irrigation management through irrigation scheduling with soil moisture monitoring devices and the promise of water savings. From the grower's perspective, the traditional water use efficiency message was based on the seemingly abstract soil physics concepts of field capacity, soil water holding capacity, plant available water and soil-moisture-characteristic curves. The installation, operation and output interpretation of these soil water monitoring devices was also daunting and tedious with many growers having difficulty seeing the link between improved irrigation scheduling and crop production returns.

The QFVG *Water for Profit* program was established in 1999 to encourage horticultural growers to improve water use efficiency and increase industry returns from irrigation. From the outset, it was clear that a traditional agronomic focus would not succeed in south east Queensland. In this portion of the state, in-field performance evaluations which focused on system hydraulics, distribution uniformity (DU) and associated crop production responses have been the key to successful grower motivation. In these analyses, DU has been closely correlated to a range of crop growth, quality and yield data. The provision of this farm specific production data has enabled growers to identify the potential crop yield and profitability benefits resulting from simple system adjustments. However, this data has also been used to develop field (and farm) specific water use efficiency and crop production functions. The ability to link these crop production functions with sprinkler irrigation models, which quantify the effects of changing the system's layout, pressure and nozzle options, has enabled the identification of cost-benefit relationships for alternative irrigation design and management practices. This data has successfully been used to stimulate grower involvement in otherwise disinterested groups. Enthused growers have modified their irrigation systems and management practices, based on recorded measurements of the engineering aspects of irrigation performance and its effect on crop yield. These changes have increased economic returns to horticultural growers in the Lockyer Valley, Granite Belt and Darling Downs by more than $30 million per annum.

INTRODUCTION

Queensland Fruit & Vegetable Growers Ltd (QFVG) are implementing the Water for Profit (WfP) program as part of the Rural Water Use Efficiency Initiative (RWUEI) for the Queensland horticultural industry. While traditional extension programs focus principally on the benefits of irrigation scheduling, this type of campaign has not been universally well received. When horticultural growers in the Lockyer Valley and the Granite Belt regions are confronted with an irrigation scheduling focus, they commonly reflect widespread beliefs that:

- "they have seen it all before";
- there is "nothing new" in the message being portrayed about irrigation scheduling; and
- they "use less water than the neighbours, so the program has little to offer them".

Motivation of these growers has required the demonstration of direct dollar benefits resulting from improved practices. These practices need to be something that they can see, touch and conduct on their properties without sales representatives and/or cost. One extension approach, which has gained irrigator support (particularly with pressurised systems) in these regions, has involved relating the irrigation system performance to the crop yield via an engineering analysis. There have been strong irrigation uniformity and crop yield correlations in most of the conducted trials. Growers appear to have responded positively to this practical engineering approach, preferring to discuss the mechanics of their irrigation system rather than the more abstract concepts of soil moisture monitoring and scheduling. This paper provides a description of the engineering approach used to create grower interest and the implications of the data obtained for investigations of irrigation water use efficiency under commercial conditions.

MATERIALS AND METHODS

The main objective of the Water for Profit Program has been to encourage growers in the adoption of improved irrigation practices. The technology transfer of engineering and distribution uniformity principles is relatively simple, universally applicable and is an excellent process to empower grower group participants. Everyone can contribute with anecdotal information and experience. Distribution uniformity and crop yield uniformity data was collected at more than 8 properties in the Lockyer Valley, Granite Belt and Darling Downs regions (Table 1). Application depth/volume data captured by catch can grids was correlated with point measurements of crop yield. The correlations were used to demonstrate the effect of distribution uniformity on crop performance and develop crop water use production functions. Options for improving irrigation system performance were identified using a two dimensional sprinkler irrigation model. The model results were combined with crop water use production functions to determine the production and economic benefits of improved system performance.

The trials were principally conducted on solid set and drip irrigation systems to eliminate the compounding influences of traveling machine speed variation, variable supply hose hydraulic performance and variable elevation head. However, four big gun traveling irrigators and the resultant crop yield responses were subsequently evaluated, due to the popularity of these systems in the Lockyer Valley. In all cases, growers were invited to be involved in the site selection and measurement process. Where possible, growers also recorded the dates and times of irrigation startup and shutoff, tensiometer readings and catch can or rain gauge data at the site.

Table 1. Crops, Irrigation Systems and Yield Measures used to Identify Crop Water Use Production Functions.

Crop	Irrigation System	Region	Yield Measure
Cauliflower	Solid set[1]	Lockyer Valley	Head diameter
Sweet Corn	Big gun traveller[5]	Lockyer Valley	Stalk height
Potato	Solid set[1] Solid set[2] Solid set[3] Big gun travellor[5] Drip[6]	Lockyer Valley	Tuber grade (diameter) and quantity
Potato	Solid set[3] Drip[6]	Darling Downs	Tuber grade (diameter) and quantity
Beans	Solid set[1] Big gun travellor[5]	Lockyer Valley	Pod number and weight
Beetroot	Solid set[1] Big gun travellor[5]	Lockyer Valley	Beetroot size and weight
Lettuce	Solid set[4]	Lockyer Valley	Head diameter and quantity
Apple	Drip[7]	Granite Belt	Fruit diameter and quantity

[1] 2” aluminium laterals spaced 14 m apart with sprinkler heads 9 m apart and 3/32” nozzles.
[2] 2” aluminium laterals spaced 11 m apart with heads 9 m apart and 3/32” nozzles.
[3] 2” aluminium laterals spaced 14 m apart with and Nelson R2000 rotators spaced 9m apart along the lateral.
[4] Lateral spacing changed from 16 m to 14 m after tuber initiation.
[5] Trailco 2-250 with a bore nozzle.
[6] T-systems 510-30-340 with 30cm spaced emitters discharging 340 L/100m nominally.
[7] Netafim pressure compensated dripper with 1m spaced emitters discharging 8.5 L/hr nominally.

Catch can analyses

For each solid set system, the irrigation application depth was measured using a grid of catch cans (Figure 1). Distribution uniformity is the evenness of irrigation applied to a crop and soil surface. There are many different measures of uniformity including distribution uniformity, emission uniformity, scheduling coefficient and the Christiansen Coefficient of Uniformity. This study used distribution uniformity (DU) because this measure is comparatively simple for growers to visualise and calculate (equation 1).

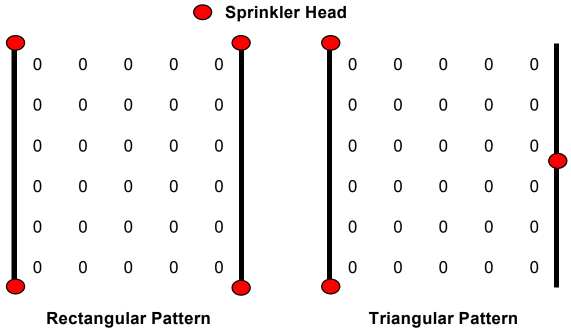


Figure 1. Catch Can Layout for DU Calculation of a Solid Set System

$$\mathrm{DU}(\%) = \frac{\text{the average of the lowest quarter of catch can measurements}}{\text{the overall average of catch can measurements}} \times 100 \qquad \text{……….(1)}$$

DU of drip laterals were measured with a container placed directly beneath each emitter to capture the irrigation discharge. Containers were typically placed under the drip lateral closest to the supply mainline and the drip lateral furthest from the mainline, as a quick system assessment for uniformity issues. The application depths for big gun travelling irrigators were measured by placing a row of catch cans across the travel path of the irrigators. The cans were located 2 m apart and the row extended out past the wetted radius of the machine to ensure all applied depths were recorded. The distance between the sacrificial laneways, colloquially known as 'tramlines', was measured. The overlap of the adjacent travellor wetted area was determined from the catch can data and the distance between tramlines.

Crop sampling and subsequent analyses

The measured crop characteristics (Table 1) were selected to represent the market quantity/quality criteria for the respective crop. However, in some cases, alternative plant growth characteristics (eg. plant height, head size) were recorded as a surrogate measure of the plant response to irrigation. For example, the relationship between head diameter of cauliflowers and head weight was determined (Figure 2). This relationship enabled faster and non-destructive measurement of the crop yield response.

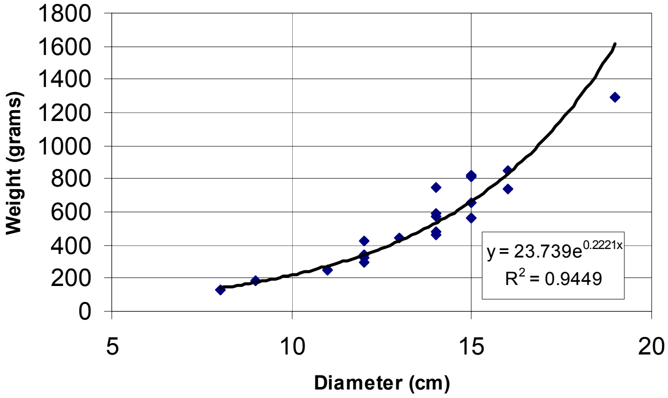


Figure 2. Cauliflower Head Diameter and Weight Relationship

For sprinkler irrigated row crops, yield and application depth grid data sets were collected and averaged as a transect across the beds in a direction perpendicular to the sprinkler lines. At least four application depth and yield measurements were collected in each bed and used as replicates in the subsequent analysis. In selected trials, a transect parallel to the lateral direction was also analysed to identify any relationship between the system's hydraulic performance and crop yield. For the drip irrigated apple crop, individual tree yield data was simply plotted against seasonal emitter discharge for that tree. Where drip irrigated row crops were evaluated, yield data was collected for at least two drip laterals and the yield data was plotted against the emitter discharge at the location of the crop sampling.

The crop production functions were developed using non-linear regressions of the recorded irrigation application volumes and the crop yield characteristic measured for each trial. It should be noted that irrigation systems which perform poorly are better suited for the development of crop water use production functions, because lower distribution uniformities provide a greater range of application volumes and crop production variability.

After the initial evaluation of the various sprinkler design packages, Space Pro (Sprinkler Profile and Coverage Evaluation Version 2.0) was selected for routine use as it allows for the input of measured grid or radial leg data and does not rely solely on the manufacturer's performance data. It also allows for the use of independently obtained radial leg distribution data for the range of sprinkler head/nozzle combinations found in the study areas. The model outputs were used in conjunction with the crop water use production functions developed above to identify the potential production and economic gains associated with improved irrigation system performance.

RESULTS AND DISCUSSION

Summary of trial results

The performance of the irrigation systems varied due to the nature of the system and the management practices adopted (Table 2). Application efficiency (AE) was typically greater than 80% although two sites recorded lower values. The DU ranged from 31 to 95% with the two highest DU values being recorded on drip tape used to grow potatoes. The lowest value was measured on an ageing drip system used to grow apples. This data confirmed that DU is one of the main reasons AE is often low, as growers tended to over-water sections of the crop to achieve a more uniform yield. In such cases, soil moisture monitoring was almost useless as the irrigation non-uniformity complicated the appropriateness of the sensor location and raised questions regarding the data validity for irrigation scheduling.

Table 2. Irrigation Performance and Potential Agronomic Gains through Improved DU.

Crop	**Irrigation System** (refer to Table 1.)	**Region**	**AE**	**Measured DU**	**Seasonal Irrigation ML/ha/yr**	**Potential agronomic gain if DU > 90 %**
Cauliflower	Solid set	Lockyer Valley	60-80%	70%	2.5	7%
Sweet Corn	Big gun traveller	Lockyer Valley	-	72%	>3.0	14% (height)
Potato (0.8ML/ha Rain)	Solid set	Lockyer Valley	80-100%	71%	1.2	21%
	Solid set		80-100%	68%	1.6	9%
	Solid set		80-100%	81%	1.2	-
	Big gun traveller		80-100%		1.7	-
	Drip		100%	95%	0.95	0%
Potato	Solid set	Darling Downs	80-100%	64%	4.5	14%
	Drip		100%	95%	2.5	0%
Capsicum	Drip	Lockyer Valley	>90%	90%	2.0	0%
Beetroot	Big gun traveller	Lockyer Valley	70%	68%	2.3	5%
Beans	Solid set	Lockyer Valley	60-80%	66%	1.8	<5%
Lettuce	Solid set	Lockyer Valley	80-100%	70%	1.1	13%
Apple	Drip	Granite Belt	50%	31%	10	0%

Relationships between uniformity of application and yield.

For each of the systems and crops evaluated, the variation in water application appeared to be closely related to the variation observed in the crop yield parameter measured. For cauliflowers (Figure 3), seasonal irrigation volumes applied across the plot area varied from 1.3 to 1.7 ML/ha. This range of applied irrigation produced head diameter differences of up to 30 mm and equivalent yield variations from 6.3 to 7.9 t/ha. For lettuce under solid set sprinkler irrigation (Figure 4), the variation in application depth was 7.4-9.4 mm/irrigation. This comparatively small variation for each irrigation translated into seasonal irrigation application volumes from 0.6 to 0.83 ML/ha and a difference in lettuce head diameters from 118 to 155 mm.

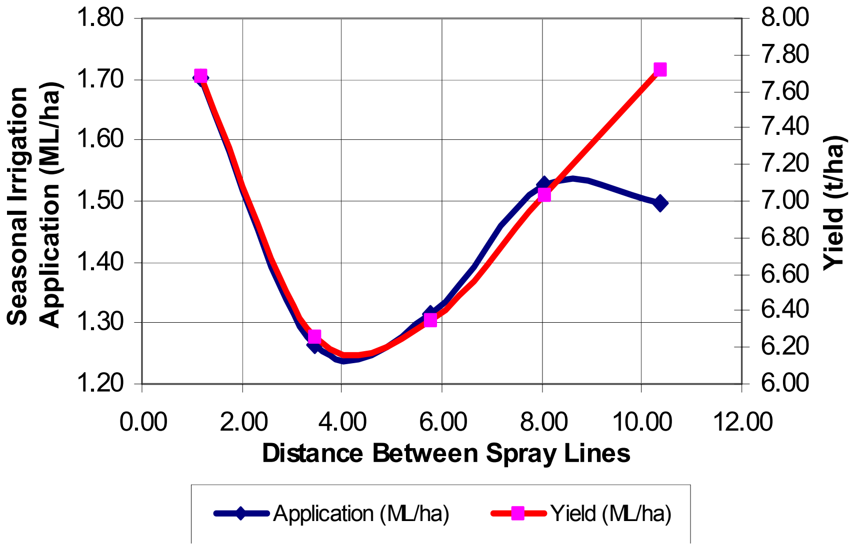


Figure 3. Variation in Irrigation Application and Cauliflower Yield between Sprinkler Irrigation Laterals

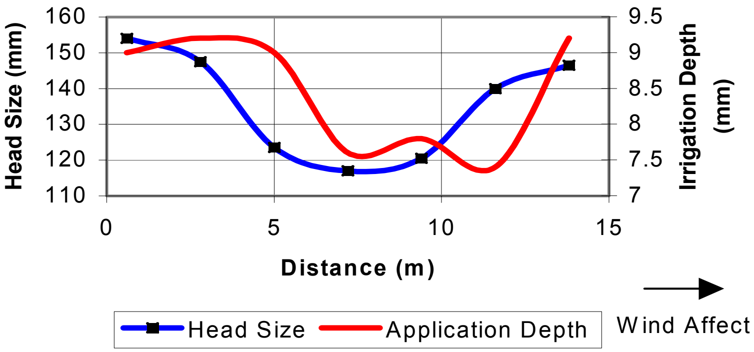


Figure 4. Lettuce Diameter and Irrigation Relationship with Wind Effects

Development of the crop production functions

The irrigation and yield data were used to identify crop water use production functions by regression analysis. In each case, crop response was significantly correlated (r^2 = 0.83-0.95) to the volume of seasonal irrigation water applied. However, the nature of the function varied between the crops. Some functions produced a decreasing marginal benefit in yield with additional water application (eg Figure 5), while others displayed either a linear or increasing marginal benefit from additional irrigation water (eg Figure 6). While significant relationships were identified in each case undertaken in this work, it should also be noted that the relationship could be more difficult to identify in cases where:

- there has been substantial in-season rainfall (ie. the effect of irrigation uniformity on the crop tends to be evened out by the rainfall); or
- the crop has a deep and/or well established root zone (e.g. older tree crops) as the root distribution may tend to compensate for non-uniformities in irrigation application.

One advantage of using the irrigation system non-uniformities to develop the crop water use functions is the reduction of potential sources of variability that are present in broad scale data including:

- current and historic cultural practices (eg. tillage, crop rotations, crop varieties, traffic);
- pesticide/herbicide applications (eg. varieties, amounts and frequencies);
- fertiliser applications (eg. varieties, amounts and frequencies);
- soil types (eg. texture, compaction, fertility) and
- irrigation practices (eg. systems, scheduling, leaching).

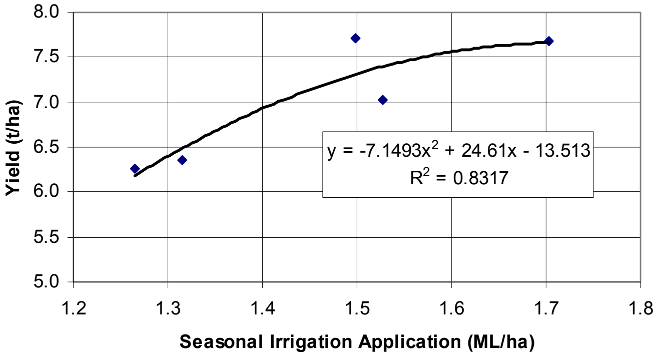


Figure 5: Irrigated Cauliflower Production Function

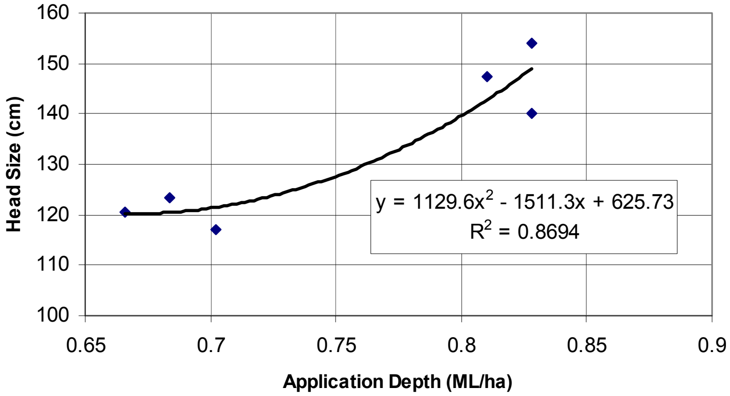


Figure 6: Irrigated Lettuce Head Performance Function

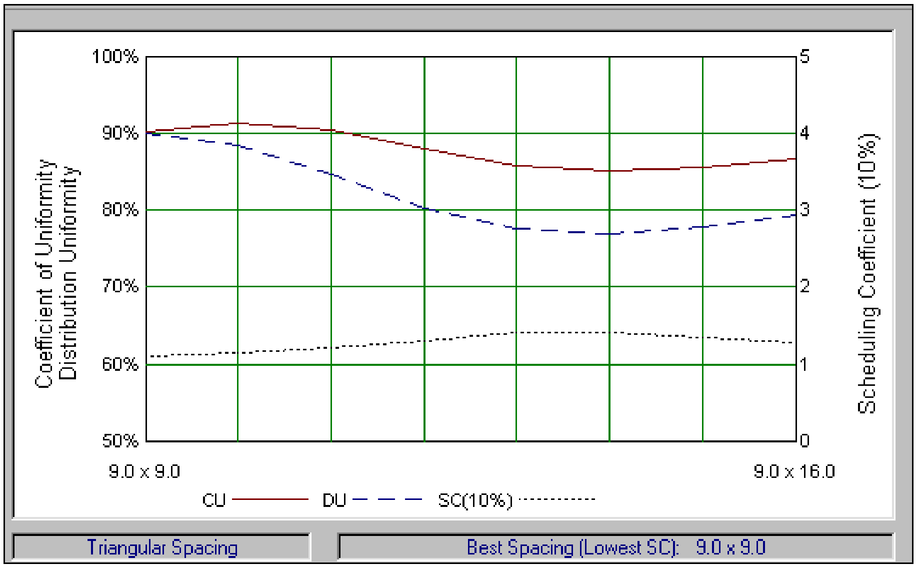
Minimising these variations assists in the adoption of improved practices by growers involved in the evaluation process because the results are directly relevant to their farms. However, the transferability of these outcomes to other farms and across the region will be greatly influenced by the magnitude of the variation in the above factors between farms. Where substantial variation in environmental, cultural or management factors is suspected between farms within a region, it would be necessary to identify the effect of these differences on the crop water use functions prior to extrapolation across the region.

Irrigation modelling and identification of appropriate strategies

Modelling the performance of alternative design and management strategies has provided a mechanism to quantify the benefits associated with the various options. The generally accepted irrigation industry minimum DU is 75%, but for higher value horticultural crops the DU should be even greater, say 85-90%. Using the models, it has been possible to evaluate the effect of various sprinkler heads, nozzle sizes, operating pressures, sprinkler head spacing and sprinkler line spacing on the DU. The potential agronomic benefit of improving DU from the existing measured levels to 90% was found to range from 0-21% for the systems evaluated (Table 2). However, the simulation of existing and alternative application systems has also helped growers to improve their decision making, through the identification of the benefits and limitations associated with the various options. Scenarios commonly investigated include:

- The minimal cost option , which was typically the effect of renewing nozzles only;
- Maintenance of the existing system option, which was the effect of changing the nozzles, sprinkler heads or the pressure only;
- Change the infield system layout option , which was the effect of changing the lateral and/or sprinkler spacing, type and/or pressure; and
- Change distribution infrastructure and/or infield system option, which was the effect of an entire system change.

For example, the effect on DU of varying solid set lateral spacing from 9 m to 16 m was investigated (Figure 7). This analysis suggests that for the specified equipment operating under optimal conditions (e.g. no wind), it is possible to achieve a DU in excess of 85% only if the lateral spacing is less than approximately 11 m. This value decreases to approximately 75% if the lateral spacing is 14 m (Figure 7 & 8) which is the most common solid set configuration currently used in the Lockyer Valley.

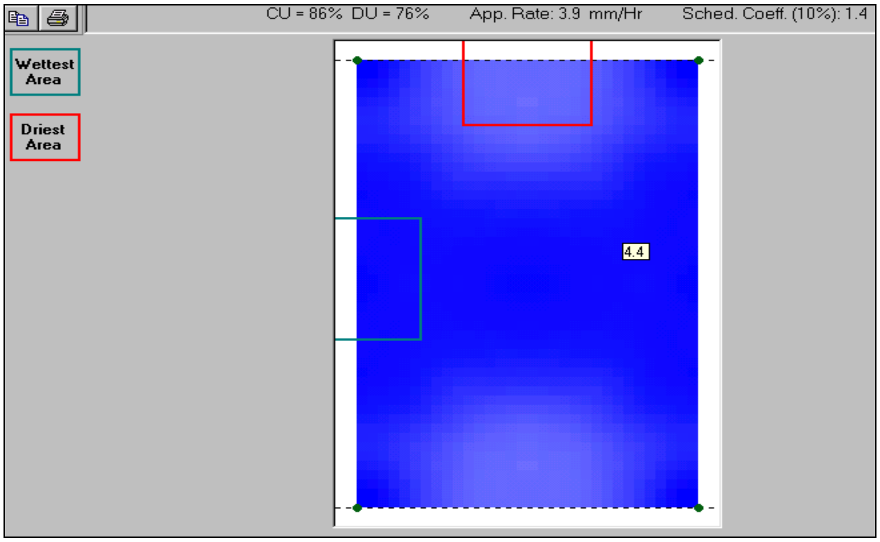


Triangular Spacing

Best Spacing (Lowest SC): 9.0 x 9.0

Figure 7: Effect of Lateral Spacing on Uniformity

(Space Pro Output -Nelson 20W sprinkler, flow control nozzle, 50 psi, triangular spacing, sprinkler heads 9 m apart)



CU = 86% DU = 76% App. Rate: 3.9 mm/Hr Sched. Coeff. (10%): 1.4

Figure 8: Densogram of Irrigation Application

(Space Pro Output -Nelson 20W sprinkler, flow control nozzle, 50 psi, rectangular spacing, sprinkler heads 9 m apart and sprinkler lines 14 m apart)

Production and economic benefits of improved performance

The distribution uniformity and crop water use production functions were used to estimate the potential yield gains available to commercial growers based on improved system design, layout and operation of their existing systems. Some of the benefits typically associated with improved DU are shown in Table 3. The DU and yield relationship, irrigation schedule and AE were used to predict whether system improvements were financially feasible (Table 4). For the majority of systems studied in the Lockyer Valley, a number of simple and comparatively cheap system modifications have been found to significantly increase irrigation profitability (Table 5).

Table 3: Factors Increasing Grower Profitability with Improved DU and Management

Increased Income	Decreased Costs
Increased consistency of produce size and quality	Reduced harvest and labour costs[2]
Increased produce yield[1]	Reduction in nutrient leaching and crop waterlogging
Able to crop additional area under water limited conditions[1]	Reduced water and pumping costs due to shorter pumping time and increased AE

[1] Assuming access to a market for the extra produce

[2] For crops that are harvested at a particular size such as cauliflower or broccoli based on more consistent produce size

[3] For improvement of existing system uniformity will typically result in decreased pump times

Table 4. Typical Economic Analysis to Evaluate the Gains from Improved Irrigation Performance

Current Water Use	3ML/ha		
Market Price	$12.50	per 25kg Carton	
Potential Yield Gain	6.4%		
Current System Efficiency	80%		
Potential Efficiency	92%		
Potential Water Saving	0.45		
Pump Pressure	70		
Application Efficiency	60-80%		
Crops per year	3		
Direct Income Benefit			
	Minimum	*Average*	*Maximum*
Yield	6.3t/ha	7.2t/ha	7.7t/ha
Income	$3125/ha	$3605/ha	$3850/ha
Agronomic Production	2.1t/ML	2.4t/ML	2.6t/ML
Economic Production	$1042/ML	$1202/ML	$1283/ML
Indirect Income Benefit			
Power Savings	$11/ha		
Fertiliser Savings	$60/ha		
Total Income Increase			**$458/ha/year**
Costs Per Hectare	*Capital*	*Life Cycle*	*Cost*
Rubbers	$288	2	$144
Damaged Heads (20%)	$290	2	$145
Nozzles	$80	5	$16
Labour	$110	5	$22
	$768		
Total Cost to Improve DU			**$327/ha/year**

Table 5: Modifications Recommended to Increase Distribution Uniformity in Pressurised Systems

System	Modifications
Solid set and hand shift	Increased pressure, decreased spacing between sprinkler lines, increased nozzle diameter, change from impact sprinklers to rotators
Boom, laterals, centre pivots	Pressure regulators at each nozzle, correct sprinkler package selection
Travelling guns	Closer run spacing, correct nozzle selection (ring, straight, tapered)

Engineering extension and benchmarking benefits

WfP employed one engineer in 1999, increasing incrementally to 4 engineers in 2001, out of 7 equivalent full-time extension officers. This shows that the Queensland horticultural industry has realized the value of engineers in agriculture, particularly in irrigation at this stage. The equivalent programs in the Queensland sugar, dairy and cotton industries each employ at least one engineer. The increase in grower and industry awareness of the benefit in assessing the engineering performance of irrigation systems has raised the irrigation sector's perspective on the value of trained engineering professionals. At the time of writing this paper (June 2002), there were five advertisements for engineers to work in the private agricultural water industry sector within a 300km radius of Toowoomba, and 6 positions available in the Queensland public sector.

The system engineering analysis of distribution uniformity and crop yield data was simple and quick to collect, which contributes to its popularity. The system and DU tests typically require less than 2 hours to setup and retrieve the catch cans, not including liaison time with the irrigator. Similarly, the crop data is normally collected in less than 2 hours and it takes between 2 and 4 hours to analyse all the data. This is much quicker, simpler and cheaper than setting up either trial plots for crop water research or long term monitoring sites. The statistical integrity of the in-field measurements could be further improved with replicate catch can layouts and additional yield measurements in the same irrigation block. For this program, it would seem to be more beneficial to increase the number of farm sites measured to improve our understanding of the "between-farm" variability and any subsequent estimate of the regional benefits of improved water use.

The horticultural sector is comparatively fragmented at the grower level due to competition in the domestic fruit and vegetable markets. This competition has resulted in relatively little information being communicated between growers as there are often concerns over the dilution of any competitive advantage associated with new technology. However, the discussion of irrigation system machinery in general, and irrigation uniformity in particular, has been perceived by growers as less threatening and mutually beneficial. This approach appears to be gaining in support from existing grower groups and seems to be analogous to attending a field day and discussing one brand of tractor in comparison to another. In these cases, the rapport and enthusiasm generated through the irrigation performance evaluations has led to subsequent grower interest in the agronomic aspects of irrigation management. This approach has been successful in the southern Queensland regions, with 62% of the QFVG Financial Incentive Scheme money spent in this region being used to fund system improvements and 38% used on irrigation scheduling equipment.

CONCLUSION

The measurement of irrigation system performance and crop responses under commercial practices has increased the interest of growers in water use efficiency. The linking of distribution uniformity and crop yield data with system performance models has also enabled substantial "value-adding" of the field data and improved the identification of irrigation production benchmarks (ML/ha, $/t, $/ha, t/ML, $/ML). This approach is directly relevant to growers and is simple enough to undertake, requiring only minimal assistance. The methodology quantifies the irrigator's the costs and benefits of improved irrigation efficiency and provides a tangible and transparent process for decision making by all stakeholders. The range of climatic variables and crop management practices undertaken by growers often complicate comparisons of local irrigation regimes. However, relating commercial distribution uniformity and yield data has highlighted the importance of irrigation as a fundamental production input that can often be managed more profitably.

The Water for Profit Program and the number of engineering positions currently advertised confirms there is a real need for engineers in agriculture. This demand appears to be related to the generic engineering focus on performance evaluation and practical solutions as well as the ability of engineers to produce numbers to support what others believe intuitively. The generation of numbers from the physical world permits funding bodies and other interested parties to assess the success of work conducted in the field through the application of financial analyses which can be relayed to the decision-makers in the corporate world. This type of analysis is often lacking in agriculture due to the nature of growers, who are practically oriented but at times lacking in formal education. The numerate skills of engineers can provide the necessary link from the practical agricultural industry to the financial focus of the government and private business sectors.

REFERENCES

1. Sprinkler Profile and Coverage Evaluation (Space Pro) Version 2.0, Centre for Irrigation Technology, California State University, Fresno USA.