# MEASURING WATER USE AND IRRIGATION SYSTEM PERFORMANCE IN THE MARY RIVER CATCHMENT

David W. Wigginton and Steven R. Raine
*National Centre for Engineering in Agriculture, University of Southern Queensland, Toowoomba*

## ABSTRACT

The Mary River Catchment lies north of Brisbane and extends from Maleny in the south to Maryborough in the north. The catchment is currently facing increasing demands for water from urban, industrial and rural water users. However, due to the unregulated water use in substantial areas of the catchment, little is known regarding the volumes of water used by agriculture and relative water use efficiency of the various agricultural users. Hence, a preliminary scoping study and subsequent on-farm irrigation performance evaluation program were undertaken to quantify the volume of water used in the catchment and to identify the potential for improvements in on-farm water use efficiency.

The volume of water used for irrigation in the Mary River Catchment was found to be approximately 62 700 ML with the dairy sector using approximately 64% of the total, sugar accounting for 25% and horticulture 11%. However, the sugar cane sector was found to apply the least amount of water per hectare (2.9 ML/ha) compared to the horticultural (3.55 ML/ha) and dairy (4.2 ML/ha) sectors. Farmers in the horticultural sector were found to have a high rate of adoption of objective scheduling techniques and irrigation systems that were perceived to increase water use efficiency. By comparison, farmers in the dairy and sugar sectors generally used comparatively low technology application systems and little or no objective scheduling techniques.

Travelling gun irrigators, solid set and hand shift sprinkler systems were evaluated during the on-farm monitoring program. In all cases, distribution uniformity, pressure and flowrate data was collected. Distribution uniformities were found to range from 1 % to 88 % for travelling gun irrigators and from 43 % to 72 % for solid set and hand shift systems. The average pressure variation during travelling irrigator runs was 11 % while the average range of pressure variation in solid set and handshift systems was 20 %. Travelling gun speeds were also found to vary considerably suggesting that significant non-uniformities may also occur in the travel direction. The implications of these findings for water use efficiency programs currently being conducted in the catchment are discussed.

## INTRODUCTION

The Mary River Catchment covers an area of 940 164 hectares (Pointon *et al.*, 1999) and is located in south-east Queensland. The Mary River has a mean annual discharge of 2 309 000 ML (Mary River Catchment Coordinating Committee, 1997), providing water for the sugar cane, dairy and horticultural industries and for the urban centres of the Sunshine Coast, Gympie and Maryborough. According to the Mary Catchment Coordinating Committee (1997) approximately 30 000 ML per year is used for town water, with more than 25 000 ML per year used for irrigation. It is expected that as development escalates in the surrounding areas of Hervey Bay and the Sunshine Coast, more water will be required from the Mary River Catchment to meet urban and industrial needs in these areas.

Within the catchment, eleven dams and weirs provide a total storage capacity of 135 785 ML (Pointon et al. 1999). While additional water storage infrastructure will be required in the future, it is the demand for water that will determine the timing of further infrastructure development. However, improvements in the efficiency of current water users may reduce both the current and future demands on the available water resources. Hence, the identification and implementation of strategies to improve water use efficiency is a tangible way to reduce water demand and delay the costs associated with the construction of future infrastructure.

Little is known regarding the amount, or relative efficiency, of on-farm water use in the Mary River catchment. The lack of information regarding the performance of existing on-farm irrigation practices in this area makes it difficult to identify improved practices and effectively target irrigation extension programs. It also creates problems for the accurate assessment of potential gains from improvements in water use efficiency. The objectives of this paper are to quantify the amount of water used for irrigation, identify current on-farm irrigation management practices and determine the potential for improved on-farm efficiencies within the catchment. The paper summarises a scoping study of available water use data, including a desktop analysis and an irrigator survey, and an on-farm experimental program.

## SCOPING STUDY

Irrigation water in the catchment is provided by a regulated system in the northern (downstream) reaches of the catchment whilst irrigators in the remainder of the catchment draw unregulated water directly from the river and its tributaries. Reasonable data relating to water use in the regulated system is available, however data for unregulated water use has not been collected. It is estimated that three sectors within the catchment comprise the majority of water used for irrigation, these being the sugar cane, dairy and horticultural industries.

### *Desktop Analysis*

The water use data available for the regulated sections of the catchment includes water allocations and metered records of actual use. Unfortunately, while the allocation data gives an excellent breakdown of allocation by use type, this data may not give an accurate reflection of the proportion of water actually used in each sector. The amount of water allocated to each sector in the regulated portion of the catchment is 34% to sugarcane, 25% to dairy and approximately 6% to horticulture. Although 13% of the water is allocated to the beef sector, it is unlikely that all of this water is used for beef cattle and therefore remains unused or is traded to farmers in another sector. It is important to note that while sugarcane accounts for the majority of allocations, this industry is only present in the northern, regulated sections of the catchment whilst the southern, unregulated sections contain dairy and horticulture enterprises.

Whilst the allocation data provides a breakdown between sectors but no indication of actual use, the water use data provides no such breakdown. Hence, determining the amount of water used by each sector would require consultation with each license holder to confirm what crop is grown in each case. However, the total amount of water delivered provides an indication of the minimum agricultural water use in the catchment. In 1996, a total of 25 296 ML of water was delivered to regulated water users and was used to irrigate a total area of 19 110 ha (State Water Projects, 1999). Water use in the unregulated sections of the catchment is not collected and allocations are calculated on an area basis rather than volumetrically.

Sugar cane production is undertaken in the northern end of the catchment with approximately 11 000 ha of cane grown on about 190 farms (P Downs and F Sestak, pers comm.). Approximately half of this area is irrigated, with 50% of the irrigated area using regulated water. Irrigation on sugar cane is undertaken primarily using high pressure travelling irrigator with benchmark application rates of 3 to 3 ½ ML/ha (F Sestak, pers comm.).

The dairy industry in the Mary River Catchment comprises 223 farms occupying a total of 28 667 ha (Pointon, et al. 1999) with approximately 7000 ha of this area devoted to fodder or forage crops. It is estimated that 156 of these farms are irrigated (W Waters, pers comm.). Spatially, the dairy sector occupies the central and southern portions of the catchment with the proportion of water obtained from the regulated and unregulated systems unknown. Similarly, horticultural production is also undertaken in the central and southern portions of the catchment. However, an accurate estimate of the area under production is difficult to obtain. The total area devoted to horticulture is likely to be between 1800 ha (Greer et al. pers comm.) and 7 717 ha (Pointon et al. 1999) with the total area divided evenly between row and tree crops. With the exception of pineapples, of which only a small proportion is irrigated, most other horticultural crops rely on irrigation. Due to the large proportion of farms in the unregulated sections of the catchment, total water use is unable to be obtained from currently available data.

This analysis of data has shown that specific industry related irrigation information is not currently available, particularly for the dairy and horticultural sectors. While some data on regulated water use in each sector is available, it is impossible to ascertain the volumes of water used from unregulated sources. Therefore, previous estimates of water use, particularly in the dairy and horticultural sectors, are likely to be inaccurate due to the uncertainty regarding the proportion of water used from these unregulated sources. There is also no accurate data relating to current on-farm irrigation efficiencies, application systems, management practices or the factors influencing water use in each sector. Conducting on-farm surveys of a representative sample of irrigators in the catchment is a valid method of collecting sufficient data to more accurately identify the irrigation volumes and characteristics within the catchment.

***Analysis of Survey Data***

A process of surveying farmers in the catchment was undertaken during June and July of 1999, to obtain, as randomly as possible, a sample of approximately 10% of farmers in each sector. The survey involved collecting data for each farm on the:

- General farm attributes (e.g. size, topography, water sources);
- Demographics of irrigator (e.g. age, level of education, computer literacy);
- Production/output (e.g. yields, returns);
- Water use (e.g. area irrigated, amount of irrigation, volume applied); and
- Irrigation drivers and farmer perceptions.

Water use for each of the industries was calculated by obtaining the number of irrigations in a season and the amount applied per irrigation and averaging this volume over the total area irrigated. Sugar cane production was found to have the lowest application rate with an average of 2.90 ML/ha applied compared to 3.55 ML/ha for horticulture and 4.20 ML/ha for the dairy industry. Variability in the application volumes was smallest between sugar irrigators with the largest variances observed in dairy and tree crop production. Water use figures provided by irrigators were for a "typical" dry year and hence should be regarded as maximum amounts likely to be applied and not averages.

From the data obtained, it was also possible to determine the value of production per ML of irrigation water applied. However, it should be noted that this represents the economic value of production to which irrigation has contributed and not the marginal economic return directly attributable to irrigation. Horticultural row crops were found to produce the greatest value of irrigated output ($12425/ML), followed by tree crops ($4095/ML) with irrigation in the sugarcane and dairy industries contributing to approximately $1000 of production per megalitre applied. However, variances in the economic value are extremely large in the horticultural industry and much smaller in both the dairy and sugar industries.

Significant differences in the type of on-farm irrigation application technique used were found between the industry sectors. While high pressure travelling irrigators were the dominant methods in the sugar and dairy sectors, these systems were only used by 8% of horticultural farmers. Horticultural producers were found to use a high proportion of micro-spray (35%) and drip (25%) irrigation systems consistent with the requirements for more precise irrigation application and management required with these crops. Surface irrigation is almost non-existent in the catchment with only minor occurrences in the dairy and sugar industries. High pressure hand-shift and solid set spray systems are used by 38% of the dairy sector and 32% of the horticultural sector.

Irrigation scheduling is not widely practiced within any of the agricultural sectors in the Mary River catchment. While 22% of horticultural producers used an objective soil-moisture measurement technique to schedule irrigations, only 5% of dairy farmers and no surveyed sugarcane farmer used any objective measure.

When asked if changes to on-farm irrigation infrastructure would increase water use efficiency, precisely half of the irrigators in both the dairy and horticultural sectors indicated that such changes would increase efficiency, compared to 80% of irrigators in the sugar sector. By contrast, 65% of irrigators in the dairy sector thought that efficiency could be improved through changes in scheduling or management practices while only approximately 30% of horticultural and sugar farmers agreed.

***Estimating Catchment Irrigation***

The total volume of irrigation water used within the catchment and the proportion applied to each sector are important factors in identifying the potential for reducing pressure on the catchment water resources by improved irrigation efficiency. The combination of farm level data collected as part of the on-farm survey process and the pre-existing catchment level land use data provides an opportunity to estimate the volume of irrigation water used by each sector. By combining these two data sources, the total volume of irrigation water used within the catchment was estimated at approximately 63 000 ML (Table 1). Of this volume, approximately 64% (40 000 ML) was attributed to the dairy sector, 25% (15 950 ML) to the sugar sector, and 11% (6745 ML) to the horticultural sector.

**Table 1. Total irrigation water use in the catchment**

| | | Water Use (ML/ha) | Average Irrigated Area (ha/farm) | Number of Farms | Total Area (ha) | Total Water Used (ML) |
|---|---|---|---|---|---|---|
| **Sugar Cane** | *Total* | 2.9 | | | 5500 | ***15950*** |
| **Dairy** | *Winter Pasture* | 4.4 | 37 | 156 | 5823 | 25619 |
| | *Summer Pasture* | 3.9 | 23 | 156 | 3606 | 14063 |
| | *Fodder Crops* | 1.1 | 2 | 156 | 297 | 326 |
| | *Total* | | | | 9725 | ***40008*** |
| **Horticulture** | *Total* | 3.6 | | | 1900 | ***6745*** |
| **Total** | | | | | | ***62703*** |

The scoping study identified that the dairy industry was found to be the largest irrigation water user in the catchment, using 64% of the total water irrigated. The volume of water applied per hectare by dairy irrigators was also found to be significantly higher than in the sugar cane or horticultural sectors, with values of up to 8 ML/ha estimated. Furthermore, the use of objective scheduling techniques in the dairy sector was almost non-existent while anecdotal evidence suggested that the high pressure application systems commonly used (ie. travelling guns) exhibited poor performance characteristics. Finally, more than half of the irrigators in this sector recognised that their water use efficiency could be improved, either through the use of better scheduling techniques, application systems or management practices. Hence, it was proposed that further work to quantify the irrigation system performance and identify strategies to improve the performance on dairy farms within the catchment should be undertaken.

## ON-FARM EVALUATION OF IRRIGATION PERFORMANCE

Data was collected for fourteen travelling gun, hand shift and solid set irrigation systems used by dairy irrigators in the Mary River Catchment. Catch can data was collected for each evaluation. Additional operating data (eg. nozzle operating pressures, discharge rates, travel speed) was also collected depending on the nature of the system being evaluated. In all cases, general background information including the equipment model, specifications, sizes, spacing and irrigation duration were collected along with operator estimates of the application volumes and system performance.

Distribution uniformity was chosen as a primary measure of system performance as high uniformity is a precursor to efficient applications and high crop yields (Pitts *et al.*, 1996). Distribution uniformity is a measure of how evenly irrigation water is applied to a crop by an irrigation event and is defined mathematically as the ratio of the average of the lowest quarter of applied depths to the average total depth of water applied (Burt *et al.*, 1997). Distribution uniformity is closely related to the system design (eg. nozzle size, operating pressure) and operational practice (eg. sprinkler/lane spacing). Where systems operate with a high level of uniformity, modification of the total water applied in an irrigation event will affect application efficiency. Hence, application efficiency is a measure that is most greatly influenced by changes to irrigation scheduling (ie irrigation timing and volumes applied) and can be readily modified providing distribution uniformity is high.

### *Travelling Gun Systems*

The distribution uniformity of the travelling gun systems was calculated using readings from catch cans located at evenly spaced (normally 2.5 or 3 m) intervals across the throw width, perpendicular to the direction of travel. The nozzle pressure was measured using a pressure transducer mounted at the tapping point located on the back of most big guns and an in-line flow meter was installed at the hydrant. A data logger recorded pressure and flowrate measurements at five minute intervals during the irrigation run. Irrigator travel speed was measured using a trailed wheel device attached to the machine.

Travelling irrigators have the potential for non-uniformities both parallel and perpendicular to the direction of travel. Lane spacing and gun rotation may influence the perpendicular uniformity whilst variations in travel speed may be a major cause of non-uniformity in the direction of travel. Additionally, variations in pressure and flowrate due to changes in elevation or pump performance may impact on both the throw distance and radial distribution pattern of the gun as well as the travel speed of the machine.

Distribution uniformity, pressure, flow and speed variation data obtained for travelling irrigators is contained in table 1. Missing data was typically due to equipment or data logger malfunction. The traveller speed sensor was not available for the entire testing period and only three recordings were obtained.

**Table 1. Performance of travelling gun irrigators in the Mary River dairy industry.**

| Site number | Distribution uniformity perpendicular to travel direction | Nozzle pressure variation along direction of travel | Flow rate variation during irrigation | Variation in travel speed during irrigation |
|---|---|---|---|---|
| 1 | 71 % | 17 % | Not measured | Not measured |
| 2 | Not measured | 20 % | 46 % | Not measured |
| 3 | 69 % | 11 % | 51 % | Not measured |
| 4 | 88 % | 8 % | Not measured | Not measured |
| 5 | 76 % | 6 % | 46 % | Not measured |
| 6 | 1 % | 6 % | Not measured | Not measured |
| 7 | 37 % | Not measured | 30 % | 51 % |
| 8 | 75 % | 17 % | Not measured | 30 % |
| 9 | 80 % | 6 % | 12 % | 12 % |
| ***Average*** | **62 %** | **11 %** | **37 %** | **31 %** |

The distribution uniformity for the travelling guns was found to range between 1 % and 88 %. Interestingly, both of these readings were obtained from the same farm and the low reading is due to a lane spacing that is far too great for the spray trajectory distance. Similarly, the system with the next lowest uniformity (37 %) also had a lane spacing that was too large for the throw of the machine. The average uniformity of all the tests was 62 %, which is well below the expected performance level for these machines. However if the fields with grossly inappropriate lane spacings are ignored, the average DU of the remaining evaluations was a more reasonable 77 %, indicating that lane spacing is a major contributor to poor uniformity. In nearly all cases, distribution uniformity could be further improved by modifying the angle of gun rotation. Many of the travelling guns tested were set to irrigate a full 360° circle, which applies more water to the centre of the distribution pattern. Changing the rotation angle to approximately 270°-330° would help to flatten out the distribution pattern and could be expected to improve the DU by a further 5-10% depending on lane spacing.

Pressure variation during the travelling irrigator runs was calculated as a percentage of the average pressure during that run. This variation ranged between 6 % and 20 %. Two of the largest pressure variations were measured on the only hardhose irrigators evaluated (sites 1 & 2) with the pressure decreasing consistently throughout the duration of the run (Figure 1). This gradual loss of pressure is consistent with the expected increase in hydraulic friction loss caused by additional coils of hose on the hose reel as the irrigator is retrieved. The large variation in pressure found at site 8 (a softhose irrigator) reflects a decrease in pressure towards the end of the irrigation (Figure 2) which was related to an increase in field elevation over the latter part of the run. However, the cause of the elevated pressure at the beginning of the run at this site is unclear. The remaining sites, in which little pressure variation (≤ 11%) was observed, were undertaken on predominantly level fields.

Flowrate measurements at sites 2, 3 & 5 were recorded as instantaneous flow rate observations where as flowrate measurements at later sites (7 & 9) were time averaged flow rates over a 5 minute observation period. Hence, while the average variation in flowrate for all of the irrigations evaluated was 37 % (Table 1), the larger variations (eg. Figure 1) are primarily due to the "noise" associated with the instantaneous readings rather than hydraulic factors. The time averaged flowrate data (eg. Figure 3) showed a considerably reduced "noise" component and trends were more readily identified. As expected, changes in the flowrate seemed to closely follow changes in elevation with flowrate decreasing as elevation increased towards the end of the irrigation run on site 7 (Figure 3).

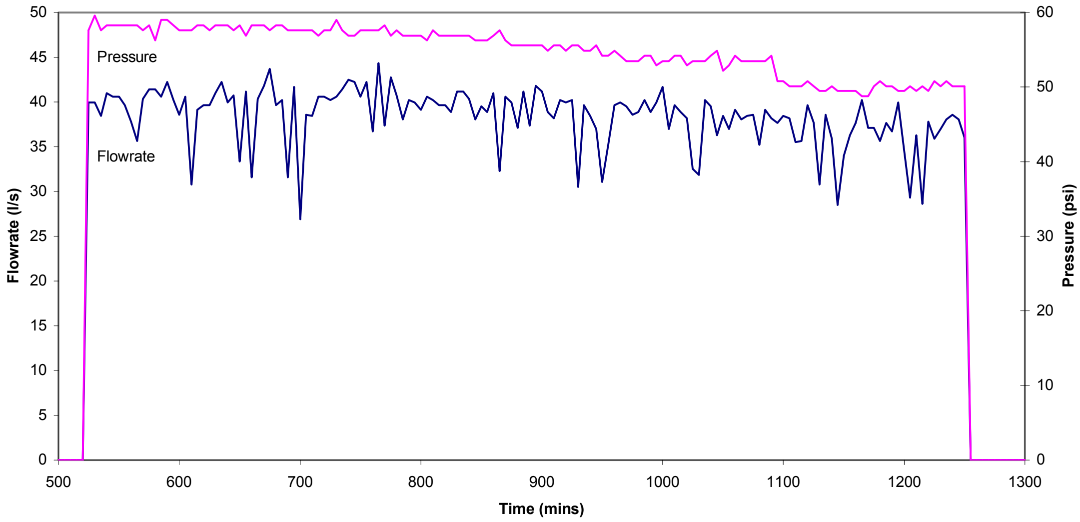


**Figure 1. Variation in pressure and flow rate for a hardhose irrigator (Site 2)**

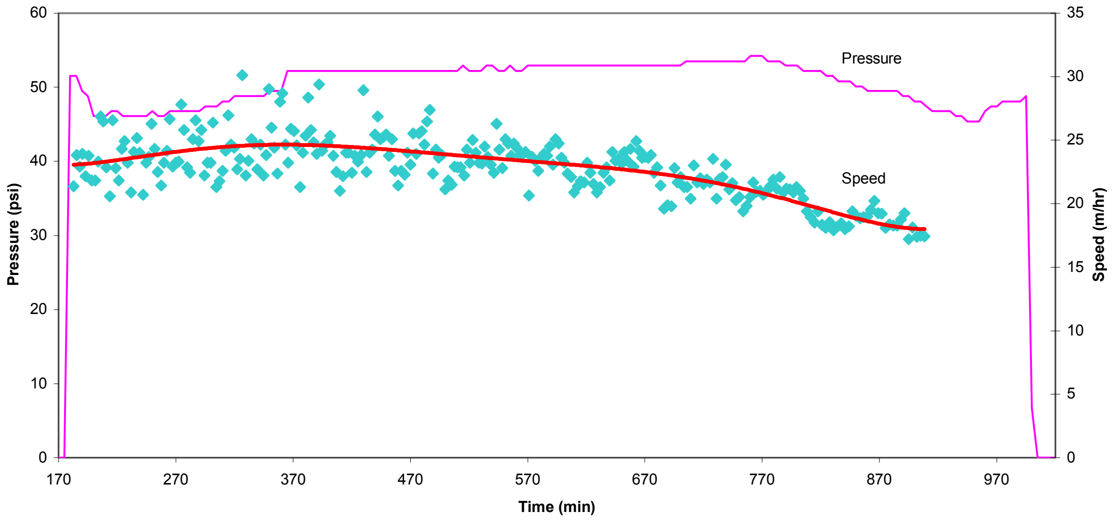


**Figure 2. Travelling gun pressure and speed during an irrigation – Site 8**

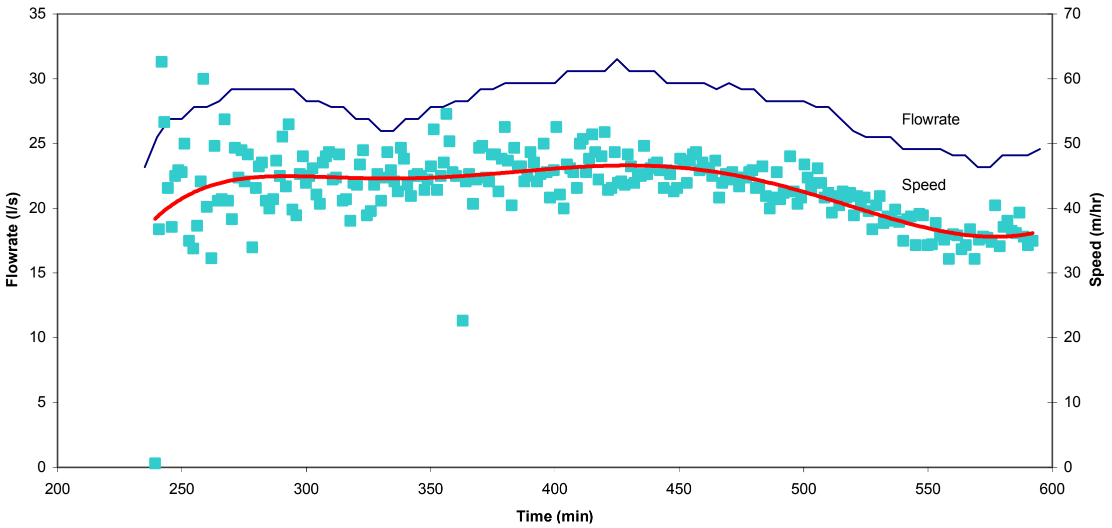


**Figure 3. Travelling gun flowrate and speed during an irrigation – Site 7**

Data from the three sites at which irrigator travel speed was measured showed that the speed varied considerably throughout the irrigation. The average variation in travel speed across all three tests was 31 %, ranging from 12 % to 51 %. The largest variations (30 % and 51 %) were obtained in fields with substantial elevation differences whilst the field in which the speed varied by only 12 % was almost level.

***Solid Set and Handshift Systems***

Distribution data for solid set systems was obtained from catch cans arranged in a grid pattern between four adjacent sprinklers. For handshift systems, the grid pattern was located between two sprinklers but extended across both sides of a lateral so that the effect of lateral spacing and overlap could be included. Additional data collected for these systems included measurements of nozzle pressure and discharge from a selection of sprinklers throughout the system. Pressure measurements were initially taken from a valve installed immediately below the sprinkler head to obtain the system pressure. Comparison of these readings and those of nozzle velocity pressure measured with a pitot tube showed differences of less than 5% (typically 1-2%). Hence, subsequent tests collected only the pitot tube reading as it was easier to obtain and more likely to be utilised in routine checks by farmers.

Sprinkler discharge was measured by recording the time taken to fill a known volume. The sprinklers bounding each catch can grid were measured along with the highest and lowest elevation sprinklers in the field and the sprinklers at the inlet and end of at least one lateral. Where this number of sprinklers did not exceed 15% of the total sprinklers in operation, additional sprinklers were sampled randomly throughout the system. Sprinkler height and nozzle diameters were also recorded in an attempt to identify the source of non-uniformities in discharge and spray pattern.

Solid set and handshift systems display similar spray characteristics with the performance being primarily influenced by system layout and operating pressure. Hence, a feature of poorly performing systems is either the presence of incorrect operating pressures for the specified sprinkler spacing or variations in pressure between sprinklers. As solid set systems are seen as permanent and could be costly to redesign and replace, improvements in performance are most readily achievable through changes in nozzle or sprinkler characteristics or by modification of pressure attributes. Handshift systems may be further modified by changes to sprinkler or lateral spacing.

Distribution uniformity, pressure and flow variation data were obtained for five solid set and handshift systems (Table 2). The physical characteristics of the solid set and handshift systems used throughout the catchment do not vary greatly with suppliers commonly adopting a consistent sprinkler spacing/nozzle configuration. Distribution uniformity was found to range between 43 % and 73 %, with an average uniformity of 62 %. However, these types of systems should be able to operate with a minimum DU of 75% and frequently in excess of 85%. Hence, the low values obtained at all of these sites suggest that there are major problems with either the design, installation or maintenance of these systems within this area. Sites 3 and 4 were conducted in fields with significant variations in elevation between sprinklers. However, the poor performance of these and the other systems evaluated seem to be primarily due to poor nozzle selection, incorrect sprinkler spacings and inappropriate operating pressures, all of which result in inadequate sprinkler overlap patterns. Pressure variation for three of the systems was excessively large, contributing to the average pressure variation of 20 %. The high levels of pressure variation evident at sites 2−4 are due to changes in elevation within the system whereas sites 1 and 5 are relatively level fields. Sites with large variations in nozzle discharge between sprinklers correspond with those systems experiencing large differences in pressure. The effect of these pressure and flowrate variations is a major cause of varying distribution patterns across the field and needs to be considered in evaluating field scale uniformity evaluations.

**Table 2. Performance of solid set and handshift irrigation systems in the Mary River dairy industry**

| Site number | Distribution uniformity | Pressure variation between sprinklers | Flow variation between sprinklers |
|---|---|---|---|
| 1 | 73 % | 7 % | Not measured |
| 2 | 61 % | 19 % | 11 % |
| 3 | 71 % | 46 % | 25 % |
| 4 | 61 % | 20 % | 18 % |
| 5 | 43 % | 6 % | 8 % |
| **Average** | **62 %** | **20 %** | **15 %** |

## CONCLUSIONS

The survey of irrigation growers in the Mary River catchment identified that the largest opportunity to improve irrigation water use efficiency and stabilize rural water demands in the catchment exist within the dairy sector. In particular, the survey found that:

- the dairy sector uses the largest proportion of irrigation water in the catchment and appears to have some of the highest rates of water application (ML/ha);
- the high variability in irrigation volumes applied suggests that there is a wide divergence of irrigation management practices in use within this sector;
- more than half of the dairy irrigators recognise that their water use efficiency could be improved, either through the use of better scheduling techniques, application systems or management practices;
- the farmers in this sector are generally younger, better educated and appear more likely to adopt new technology than in the other sectors; and
- the level of farmer knowledge regarding application technology and management practices is generally low, and irrigation scheduling is not widely used.

The performance of on-farm irrigation systems utilised by the dairy industry in the Mary River Catchment has been investigated. Only 30% of the applications systems tested achieved distribution uniformity values greater than the widely regarded acceptable minimum of 75% and only one system was performing at the desirable level of >85%. For travelling gun systems, significant improvements in performance could be made relatively simply by better matching of lane spacings to the machine requirements. However, many of the solid set and hand shift systems within the catchment have been inappropriately designed. In these cases, improvements in the performance of these systems will be dependent on redesigning the systems which may involve comparatively minor changes to sprinkler heads, nozzle sizes and/or operating pressures, or more substantial changes of sprinkler spacing, hydrant spacing and/or the supply hydraulics.

## REFERENCES


Burt, C. M., Clemmens, A. J., Strelkoff, T. S., Solomon, K. H., Bliesner, R. D., Hardy, L. A., Howell, T. A. and Eisenhauer, D. E. (1997) *Irrigation Performance Measures: Efficiency and Uniformity*, Journal of Irrigation and Drainage Engineering, November/December 1997, pp 423-442.

Downs, P. (pers. comm.) *Cane Supply Manager, Maryborough Sugar Factory,* Maryborough, April 1999.

Greer, N. G., Broadley, R., Newett, S. and O'Hare, P. (pers. comm.). *Senior Extension Horticulturalist, Department of Primary Industries,* Nambour, April 1999.

Mary River Catchment Coordinating Committee (1997). *Mary River Catchment Strategy*, Department of Natural Resources, Gympie.

Pitts, D., Peterson, K., Gilbert, G. and Fastenau, R. (1996) *Field Assessment of Irrigation System Performanc*e, Applied Engineering in Agriculture, Volume 12 Number 3, pp 307-313.

Pointon, S. M., Dwyer, G. T. and Collins, A.W. (1999). *Mary River Catchment Land Use Study*, Department of Natural Resources. Gympie.

Sestak, F. (pers. comm*.) Cane Productivity Officer, Cane Pest and Productivity Board,* Maryborough, March & April 1999.

State Water Projects (1999). *Lower Mary Irrigation Area and Mary Valley Project - Yield Assessment Report*, Department of Natural Resources, Brisbane.

Waters, W. (pers. comm.). *Dairy Extension Officer, Department of Primary Industries,* Gympie, July 1999.

Wigginton, D.W. and Raine, S.R. (1999) *Irrigation and Water Use Efficiency in the Mary River Catchment: A Scoping Study,* National Centre for Engineering in Agriculture Publication 179729/3, Toowoomba.