NCEA

RWUE Project 10

Development of Diagnostic "Toolkits" for the Evaluation and Improvement of Mobile Sprinkler Irrigation Systems

Final Report

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EXECUTIVE SUMMARY

Sprinkler irrigation is a significant form of water application in Queensland irrigated agriculture, particularly in the sugar and dairy industries, and adoption of the mechanised form (travelling gun, short boom, centre pivot and lateral move machines) is increasing across all industries. However poor performance, particularly poor uniformity, is one significant factor limiting the successful adoption of these machines.

This project was established with the express aim of addressing this poor performance. Its focus was the development of diagnostic tools, encompassing field measurement procedures and appropriate simulation models, to aid in the diagnosis and correction of design, operational and management problems associated with these machines.

The project has in large part met all of its objectives and has resulted in:

- a training course on sprinkler systems evaluation (run in conjunction with the 2001 IAA Regional Conference in Toowoomba);
- published reviews of the use and performance of both travelling gun and large mobile machines (centre pivot and lateral move machines);
- field measurements benchmarking the performance of these machines across the range of industries comprising the RWUE program;
- very substantial and significant interaction with and support for the RWUE Adoption Program;
- development of the decision support program TRAVGUN for the selection of preferred travel lane spacings and nozzle sector angles for travelling gun machines;
- evaluation of programs designed to model the hydraulic and irrigation performance of centre pivot and lateral move machines, and selection of the preferred models; and
- development of the SpanGEN and mBOSS models which, in conjunction with the commercially available Sprinkmod and Sirias models, comprise the diagnostic system for centre pivot and lateral move machines.

The report on this project is deliberately very brief. All, but the latest element of the project, have been the subject of published reports and papers, copies of which are included as attachments to this report. The other main products of the research, the computer simulation models (TRAVGUN, SpanGEN for Sprinkmod, & mBOSS) and their respective user guides, are also included as attachments to this report.

Despite the success of this project and the formal conclusion of the RWUE Research and Development Program, work on this topic has not concluded, viz:

- Papers on the TRAVGUN model and on the hydraulic modelling of the large mobile machines are being prepared for journal publication.
- A study involving laboratory and field measurements, supported by simulation is underway to address the influence that ageing and malfunctioning components (such as, pressure regulators and nozzles) have on the performance of the large machines.
- NCEA has received some limited funding from CRDC for 2003/04 to support the adoption of centre pivot and lateral move machines in the cotton industry with a view to a much-expanded project in 2004 and beyond.

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Attachment B Smith, R.J., Baillie, C. and Gordon, G. (2002) *Performance of travelling gun irrigation machines.* Proc Australian Society of Sugar Cane Technologists, 24: 235-240.

Attachment C Newell, G., Foley, J. and Smith, R.J. (2002b) *A sprinkler pattern model for travelling gun irrigators*. Irrigation Australia 2002, Irrigation Association of Australia, Sydney, 21-23 May 2002.

Attachment D TRAVGUN: Travelling Gun Simulation Model Version 1.2 plus User's Manual. (CD)

Attachment E Newell, G. (2003) TRAVGUN: Travelling Gun Simulation Model – User's Manual and Technical Documentation. *NCEA Publication 179764/3*.

Attachment F Foley, J.P. and Raine, S.R. (2001) Centre pivots and lateral move machines in the Australian cotton industry. *NCEA Publication 1000176/1*.

Attachment G Foley, J.P. and Raine, S.R. (2002) *Centre pivot and lateral move machines in the Australian cotton industry.* Irrigation Australia 2002, IAA, Sydney, 21-23 May 2002.

Attachment H Foley, J. (2001) Initial Benchmarking Reports for Centre Pivots, Travelling Booms and Lateral Moves. *NCEA Publication 179764/2.*

Attachment I Simulation package for centre pivot and lateral move machines: Programs (**SpanGEN for Sprinkmod**, **mBOSS**, and **SIRIAS**) and **User Guides**. (CD)

1. INTRODUCTION

Sprinkler irrigation is the dominant method of water application in the Queensland sugar, dairy and horticultural sectors. In the sugar industry, approximately 48% of irrigators use travelling guns. This number increases to 75% outside the Burdekin, which is almost exclusively furrow-irrigated (Tilley & Chapman, 1999). In the horticultural sector, only 6.3% of irrigated growers used travelling guns and 3.5% use travelling booms (Barraclough, 1999). In the dairy industry travelling guns are used by 53% of irrigators, with a further 41% using either fixed, centre pivot or lateral move systems (Barraclough, 2000). Low-pressure overhead mobile systems are also finding use in the cotton and grains sector with 11% of cotton growers using centre pivot or lateral move systems. About 15% of irrigators in the grains sector use either travelling gun or boom machines (Goyne *et al*., 2000).

Despite this heavy dependence on sprinkler irrigation, the in-field performance evaluation of commercial systems is rarely conducted. While the application efficiencies of commercial sprinkler systems are commonly believed to be around 60-75% preliminary evaluations conducted on water winches in the sugar industry have found some systems operating with uniformities of less than 50%. Application uniformities measured under winches elsewhere have shown less than 20% of machines give satisfactory performance. Similar poor performance has been reported for some centre pivots and lateral move machines (CP&LMs). This suggests that the development and promotion of appropriate evaluation and diagnostic tools to assess and monitor sprinkler irrigation performance under commercial conditions will provide significant improvements in irrigation uniformities and efficiencies.

High technology irrigation methods such as lateral move, centre pivot, and LEPA machines have increasingly been recommended as a solution to the low efficiencies of Australian irrigated agriculture as these machines offer the potential for efficient and uniform irrigation applications. However, sub-optimal performance due to either inadequate or inaccurate hydraulic design, poor matching with the requirements of the crop and the soil intake rate, and the lack of any procedure for evaluation and diagnosis, has hindered adoption of this technology. Previous work has resulted in a range of computer models for the evaluation of the hydraulic and irrigation performance of these machines. When coupled with the necessary and appropriate field measurements, these models provide the basis for a practical and cost efficient on-farm evaluation and diagnostic procedure.

2. OBJECTIVES

The overall aim of the project was to develop and implement a suite of procedures designed to aid irrigators and extension staff in the diagnosis and correction of design, component, operational or management problems with mobile sprinkler irrigation systems. Consistent with these aims the project had the following specific objectives:

- Identify the operational problems and performance deficiencies experienced by sprinkler irrigators, the key performance parameters/variables and the means for their measurement;
- Benchmark the performance of mobile sprinkler machines (travelling irrigators, lateral move, centre pivot, LEPA, and short booms) across a range of soils, regions, and industries;
- Combine the field observations with existing simulation models to provide simple/effective diagnostic procedures; and

- Develop and produce "farmer-friendly" measurement and diagnostic "toolkits" in close collaboration with the RWUE adoption program staff.

3. TRAVELLING GUN IRRIGATORS

3.1 Review

A substantial review was undertaken (Newell *et al.,* 2002a) with the aim of identifying the variety of problems that influence machine performance and management. Techniques and tools used to assist in improving irrigation performances were also reviewed, along with manufacturers' data and recommendations for operation of these machines. Future research needs were also considered.

A copy of the review is included in this report as Attachment A.

3.2 Benchmarking

To redress the deficiency in local data on machine performance, trials were conducted in the Bundaberg region to determine the performance of travelling irrigators under various conditions and to enable assessment of the opportunities for improving performance (Smith *et al.,* 2002). Depths of water applied by one pass of the machines were measured using a linear array of catch cans in a single leg test. The Christiansen uniformity coefficient (*CU*) was used to benchmark the performance. The influence of wind speed and direction (relative to the travel direction of the machine), operating pressure, and nozzle size and type were determined.

All trials were performed on Bundaberg Sugar properties. The first six trials were undertaken on the Avondale plantation and the remaining sixteen at Fairymead. The soils at Avondale were light sands and at Fairymead were heavy alluvial clays. Both farms are in close proximity to the coast and experience unobstructed sea breezes.

The irrigators tested were all Trailco Traveller, T450-2 machines, typical of those used throughout the Bundaberg region. All were fitted with Nelson P200 guns with a 21º trajectory angle. The machines were set up and operated as per normal grower operation. The drive mechanisms were set to give a travel speed of 20 m/h and the rotation angle of the guns set at 330º.

Based on the results of the 22 trials, with CU range of 48.3 to 84.5% and a mean of 72%, strategies to improve performance have been proposed as follows. Incorrect or excessive travel lane spacing was identified as the key issue. To maximise the uniformity of their irrigations, Bundaberg growers would need to reduce their lane spacings substantially, to between 60 and 65 m if they intend to irrigate only in low wind conditions, and to around 50 to 55 m if they intend to irrigate in all wind conditions.

For many established growers, reducing lane spacings will be impractical. Lane spacings have been fixed by limitations imposed by the farm layout and water supply infrastructure. In these instances other strategies need to be adopted to give improved uniformity such as changing to tapered nozzles and/or altering the angle of rotation of the gun.

Tapered nozzles have been shown to increase the wetted radius in all wind conditions and hence increase the overlap of adjacent passes of the machine. Uniformity is increased as a consequence.

The commonly used 330° angle of rotation of the nozzle appears to have a pronounced effect on the uniformity of applications. Improvements in performance for the present lane spacings and for high wind conditions may result most simply from a reduction in the angle of rotation.

This work was reported at the 24th ASSCT Conference (Smith *et al.*, 2002) and a copy of this paper is included in this report as Attachment B.

3.3 Diagnostic Model

The decision support model TRAVGUN (Newell, 2003) has been developed to allow selection of preferred travel lane spacings and nozzle sector angles for traveling gun machines. It combines: (i) a semi-empirical model of the wind distorted sprinkler pattern; (ii) a novel calibration procedure using field measured transects for the particular machine; and (iii) site specific wind data, to give estimates of the seasonal uniformity of applications for various values of lane spacing, travel direction and sector angle.

The basis of the program is the semi-empirical sprinkler pattern model developed at Cranfield University in England (Richards and Weatherhead, 1993 and Al-Naeem, 1993). The model calculates the wind drift and range shortening effects on the sprinkler pattern from a gun in windy conditions and provides a realistic estimate of the wind-distorted pattern of applications. In general terms, wind lengthens the sprinkler distribution pattern downwind, shortens the distribution pattern upwind and narrows the distribution pattern at right angles to the wind direction (Shull and Dylla, 1976).

The model requires a radial leg sprinkler pattern in no wind conditions and the six factors used to describe the wind drift and range shortening caused by wind. These are determined from simple field measured transects using a novel calibration procedure developed specifically for TRAVGUN. The model and calibration procedure are described in detail in Newell (2003).

Outputs generated from the program include:

- a no wind sprinkler distribution pattern,
- a wind affected sprinkler distribution pattern,
- a single run transect showing the depths applied by a single pass of the machine,
- an overlap transect that results from overlapping adjacent passes of the machine,
- a seasonal cumulative distribution curve of applied depths between the travel lanes, and
- plots of uniformity versus sector angle, lane spacing and travel direction.

All outputs are available in graphical or numerical (save to file) form.

Trial simulations undertaken with the model (Newell *et al.,* 2002b) have indicated substantial potential benefits over an irrigation season from reducing sector angles from the usual 330° to somewhere in the range from 210° to 240°, particularly when lane spacings are excessive, and under fluctuating wind conditions. It was also shown that for seasonal wind data, travel lane orientation perpendicular to the prevailing wind is recommended.

Copies of the paper (Newell *et al.,* 2002b), the TRAVGUN program, and the User Manual are included in this report as Attachments C, D and E, respectively.

NCEA will continue to train and support users of the TRAVGUN program.

4. CENTRE PIVOT AND LATERAL MOVE MACHINES

4.1 Review

A review and intensive directed survey (Foley and Raine, 2001) was conducted encompassing over 75 centre pivot and lateral moves (CP&LMs). Included in this document is a general background to these machines, an overview of their structure and operation, and a review of important performance measures for these machines. Results from this work show that over half of the surveyed CP&LM growers would like to make changes to the design of their machine in the future, while 65% of respondents have moved to this irrigation technology because of the improved uniformity performance over furrow irrigation (Foley and Raine, 2002). Myths regarding CP&LM performance abound (Raine and Foley, 2001), but these machines have the capacity to radically improve irrigation performance levels across the irrigated regions of Queensland if designed, installed and managed well.

Copies of the review report and the subsequent paper presented at the 2002 IAA conference in Sydney (Foley and Raine, 2002) are included in this report as Attachments F and G, respectively.

4.2 Benchmarking

The irrigation performance measure for CP&LMs upon which this project has concentrated is uniformity. For CP&LMs, uniformity, which is the measure of the variation in the depth of applied water, is of greater importance than any of the other performance measures such as efficiency (Heermann and Kohl, 1980). Uniformity is solely dependent upon the operating parameters and the hydraulic design of the system.

Testing of CP&LMs in the early phases of this project highlighted the poor performance of these machines (Foley, 2001) with uniformity coefficients as low as 49.7%. Uniformity coefficients from CP&LMs should exceed 90%, a performance level with which sprinkler and machine manufacturers readily agree (Raine and Foley, 2002) but a level that is infrequently attained in field. The uniformity of CP&LMs in the US is also variable (Schneider, 2000). Values of the Heermann and Hein coefficient, CU_{HH} ranged from 70% to 86% for approximately 107 machines. Unpublished Australian work on 22 centre pivots shows similar performance levels to the US results (Sparrow & Christie, PIRSA, SA and Sutton, QDO & Dairy RWUEI). These centre pivots produced results ranging from 65.2% up to 91.4% for CU_{HH}. Two studies by Schneider (2000) have reported uniformities for LEPA equipped pivots, with CU_{HH} between 94 and 97%.

Application efficiencies for these modern CP&LM machines are very high, especially when low-pressure modern sprinklers or LEPA techniques are employed (Schneider, 2000). Application efficiency is essentially a management or scheduling issue and is beyond the scope of this project. The CP&LMs included in the earlier review (Foley and Raine, 2001) show substantial numbers were under capacity and had no ability to over irrigate and operate inefficiently.

4.3 Simulation Models

As the area irrigated by CP&LMs increases across the state, a simpler process to validate the irrigation performance of CP&LMs has become essential. Catch-can testing of large machines is a laborious and tedious process, which if not performed rigorously can give results that may mislead.

The data necessary for diagnosing or simulating the irrigation performance CP&LMs include: the elevation, radial or longitudinal distance, internal diameter and head-discharge characteristic of nozzles; the hydraulic characteristics of pipelines supplying the nozzles; operating characteristics of the pump; the pressure response function of the pressure regulators; the radial leg sprinkler distribution; and the speed and direction of the wind at the machine location over the growing season.

From these data the resulting distribution of irrigation water on all parts of the irrigated field can be realistically predicted. More importantly, the simulation of alternative machine configurations should be possible where existing installations are performing poorly.

In considering the uniformity of water being applied by these machines, there is a necessity to consider two distinctly different scales of analysis. The larger scale is across the whole width of the machine and can be analysed from an understanding the hydraulic behaviour of the system and the resulting uniformity of the nozzle outflows. The second scale on which uniformity needs to be considered is at the spacing of a small number of overlapping sprinklers. The uniformity generated at this scale is solely attributable to the manner in which sprinkler patterns interact and generate the pattern of water applied to the soil surface as the machine moves past any given point in the field.

In Table 1 below, the models evaluated for inclusion in the final system are listed along with their key characteristics. These models fall into three separate categories: those that analyse the system hydraulics, those that simulate the sprinkler distribution and those that do both. As expected, the models vary considerable in their complexity and data requirements and in the nature and quality of the results generated. Those chosen for further rigorous testing were:

- CPED (Heermann, 1990) and Sprinkmod (Anrade and Allen, 1999) for the hydraulic analysis; and
- Lateral (Kinkaid, 2000), Sirias (Carrion *et al.,* 2001 and Montero *et al.,* 2001) and SpacePro (Oliphant, 1999) for sprinkler distribution.

Sprinkmod (Anrade and Allen, 1999 and Anrade *et al., 1999*a & b) emerged as the preferred hydraulic model. This model was designed to simulate the hydraulic performance of a wide range of sprinkler irrigation systems, including CP&LMs. The evaluation/testing showed that it uses a rigorous and accepted hydraulic theory and produces accurate and repeatable results. The major difficulty in its use with CP&LMs is the massive quantity and complexity of the input data, particularly in relation to the span geometry, and the time taken to construct the data file for any particular system.

Table 1: CP&LM simulation models assessed in study.

CP&LM Model	Language	OS	Units	Hydraulic Analysis	Sprinkler Distribution	Available	Adequate Function
Winchart	English	Win	US	Y[1]	N	N	N
Senninger	English	Win	US	Y[1]	N	N	N
V2O	English	Win	SI	Y[1]	N	N	N
Niwasave	French	Unix	SI	Y	Y[2]	N	N
Irricad	English	Win	SI	N	N	$12K	N
Wcadi	English	Win	SI	N	N	$30K	N
CPIVOT	Spanish	Win	SI	Y	Y[2]	N	N
CPED	English	Win	US	Y	Y[2]	Y	N
Sprinkmod	English	Win	SI	Y	N	$550	Y
Sirias	English	Win	SI	N	Y[4]	freeware	Y
SpacePro	English	Win	SI	N	Y[3]	$900	Y
Lateral	English	DOS	SI	N	Y[2]	Y	N
Catch3D	English	DOS	SI	N	Y[3]	Y	N
LMHyd	English	DOS	SI	Y	Y	Y	N
LMDep	English	DOS	SI	N	Y[2]	Y	N

Notes:
1. Commercial nozzle selection package
2. Sprinklers on moving boom
3. Overlap of fixed sprinkler pattern
4. Wind affected single sprinkler pattern

This has been overcome to a substantial degree with the development, by the project team, of the program SpanGEN for Sprinkmod. This program, written in Borland Builder C++, is a graphical user interface that builds input files for Sprinkmod specifically for the simulation of centre pivot and lateral moves. It allows users to quickly assemble a simulation file for Sprinkmod for very large CP&LMs, using standard spans and standard components (pumps, fittings, droppers, nozzles and pressure regulators).

To diagnose system performance, CP&LM components (pumps, sprinkler nozzles, pressure regulators) can be modelled in an “as manufactured state” or in a worn or used state, subject only to the availability of data on the performance characteristics of these components in the appropriate state.

A copy of SpanGEN for Sprinkmod and its User Guide is included in this report as Attachment I. Users will be required to purchase their own copy of Sprinkmod from Utah State University.

The package developed to simulate the overlapped spray patterns of CP&LMs and hence predict the uniformity of applications for a particular machine and nozzle configuration is based on the Spanish sprinkler pattern model Sirias (Carrion *et al.,* 2001 and Montero *et al.,* 2001). For a given no-wind radial leg pattern (for a particular nozzle, pressure and elevation), Sirias is used to generate a wind-affected spray pattern for a given wind speed and direction. This pattern is then taken by the in-house program mBOSS, rotated and overlapped as required to calculate the pattern of applied depths and hence uniformity coefficients for different sprinkler spacings and wind directions.

Copies of mBOSS and Sirias (freeware) are also included in this report as Attachment I.

NCEA will support users of the CP&LMs simulation package (Sprinkmod, SpanGEN for Sprinkmod, mBOSS and Sirias) and will provide training for potential users as required.

5. CONCLUSIONS

The work undertaken in this project has addressed all of the project objectives with a substantial degree of success, as follows:

Objective 1: Reviews covering the use and performance of both travelling gun and the large mobile machines were published and distributed. These reviews identified the key operational difficulties and performance deficiencies experienced by sprinkler irrigators and provided a firm direction for the work to follow.

Objective 2: Benchmarking measurements on both travelling irrigators and the large mobile machines have confirmed that the performance of these machines falls far below their potential. Factors such as lane spacing, nozzle type and sector angle were identified as key factors contributing to this poor performance in the case of travelling irrigators. For the large mobile machines factors included; excessively low operating pressures, poor pump selection and poor nozzle selection and spacing.

Objective 3: The TRAVGUN decision support program was developed to aid in the selection of preferred travel lane spacings and nozzle sector angles for travelling gun machines. This model determines the uniformity of applications over the whole field and whole irrigation season, taking into account the wind pattern for the particular location. Calibration of the model is from simple field measured transects of applied depths.

For the large mobile machines the proposed diagnostic package consists of two parts, viz: Sprinkmod and SpanGEN for Sprinkmod for the hydraulic analysis; and Sirias to determine the wind affected sprinkler pattern for a single nozzle, with mBOSS to overlap the sprinkler patterns to give the pattern of depths applied by the machine.

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