A Decision Support Model for Travelling Gun Irrigation Machines

R.J. Smith[1)], M.H. Gillies[1)], G. Newell[1,2)] and J.P. Foley[1)]

[1)] National Centre for Engineering in Agriculture and Cooperative Research Centre for Irrigation Futures, University of Southern Queensland, Toowoomba, Queensland, 4350, Australia, Tel. +61 7 46312510, Email: smithrod@usq.edu.au

[2)] Present address: Hydraulics & Hydrology Engineer, Maroochy Shire Council, Maroochydore, Queensland, 4558, Australia

Introduction

Travelling gun irrigation is a popular form of irrigation in the Queensland dairy, sugar and horticultural industries. High uniformity of irrigation applications is essential to the production of high yields from these crops however, poor uniformity is characteristic of travelling gun machines. For example, Smith *et al.* (2002) reported that only 25% of machines tested in sugar cane areas near Bundaberg, Qld, gave uniformities greater than the recommended Christiansen Coefficient of Uniformity (CU) of 80%.

Simulation of the sprinkler distribution pattern from a travelling gun provides the basis for a powerful and effective decision support model for these machines that will assist extension staff in the development and promotion of optimum irrigation management strategies. Central to the simulation is the prediction of the impact of wind on the sprinkler patterns.

Modelling Gun Performance

Simulation of sprinkler irrigation distribution patterns in windy conditions has evolved significantly over the past two decades. Two major approaches have been used, a deterministic ballistic approach, which applies traditional ballistic theory to calculate the flight trajectories of individual water droplets, and empirical methods, which involve extrapolation from measured sprinkler distribution patterns for various wind speeds and directions for the same nozzle, pressure and trajectory angle.

Although modelling of sprinkler distribution patterns is now commonplace, few attempts have been made to apply either approach to travelling gun nozzles. The first major work was that of Richards and Weatherhead (1993) who developed an empirical model that allowed prediction of the distortion of the sprinkler pattern by wind. This model was developed further by Al-Naeem (1993) with the inclusion of wetted sector angles other than 360°. The model uses a complex series of algorithms and six empirical parameters to convert a measured no-wind pattern into the wind-distorted pattern. Data required for the calibration of their model are a full-circle pattern or radial leg in still conditions, and two full-circle wind distorted patterns obtained in different wind conditions.

Augier (1996) applied the ballistic approach, treating the jet trajectory as a multi-phase plume, to simulate sprinkler distributions from a gun with variable sector angle. Similarly, Grose (1999) used a three-dimensional two-phase plume, which consisted of modelling the interaction of the jet with the surrounding air, simulating the separation of the jet into individual droplets and determining the ballistics of the individual droplets after their separation from the plume.

Both the ballistic and empirical methods have been shown to produce adequate results after calibration (Grose, 1999). The empirical method requires substantial field data for each nozzle configuration, whereas the ballistic approach can simulate a greater range of configurations without repetitive data collection. However, expensive equipment is required to collect the drop size distributions necessary for the ballistic model, the cost of which would be prohibitive for most researchers.

The empirical approach was selected in the present study as the best option for an extension or decision support tool, because it offered the ability for calibration for a particular configuration using a simple field procedure and inexpensive equipment.

Empirical Sprinkler Pattern Model

The sprinkler pattern model selected as the basis of the decision support system TRAVGUN is that of Richards and Weatherhead (1993) as modified by Al-Naeem (1993). In this model the distortion of the sprinkler pattern by wind reflects the results of both wind drift (W_D) and range shortening (R_S). These two factors are described by six constants, which Al-Naeem (1993) estimated from measured sprinkler patterns. The distortion of the sprinkler distribution pattern perpendicular to the wind direction involves range shortening only, whereas the distribution parallel to the wind direction upwind and downwind of the gun is dependent on both wind drift and range shortening. These two characteristics are given as functions of the zero wind sprinkler distribution:

$$W_D = \left[A + B\left(\frac{r}{R_m}\right) + C\left(\frac{r}{R_m}\right)^2 \right] W \quad \text{and} \quad R_S = \left[D\left(\frac{r}{R_m}\right) + E\left(\frac{r}{R_m}\right)^2 + F\left(\frac{r}{R_m}\right)^3 \right] WS$$

where *A, B, C* are the wind drift constants for the particular gun setting; *D, E, F* are the range shortening constants; R_m is the maximum wetted radius under zero wind conditions; *W* is the wind speed (m/s); and *S* is the Sine of the three-dimensional angle between the direction of the water jet and the wind direction.

Calibration

Alternative Approach to Calibration

The calibration procedure for the original model of Richards and Weatherhead (1993) and Al-Naeem (1993) is time consuming, expensive and impractical, requiring a dedicated facility for measuring the wetted patterns in quiescent and windy conditions.

TRAVGUN employs a novel calibration requiring measurements taken in the field under normal operating conditions, using equipment available to most irrigation extension staff. This approach has the advantage that the calibration is relevant for the particular nozzle, pressure and height. A minimum of three measured transects (perpendicular to the travel path of the machine) of depths applied by the machine in a single pass are required, one of which one must be obtained in quiescent conditions. The other transects can be collected for any wind speed and direction, however, it is essential that wind speed and direction during each test remain relatively constant.

A two part inverse solution is used in the calibration. Firstly, the radial leg sprinkler pattern for the machine is determined from the transect measured in quiescent conditions, and then secondly, the six wind parameters are calculated from the two transects measured under different wind conditions by minimising the difference (as expressed by the RMSE) between the measured and predicted transects.

Radial Leg from Measured Transect – an Example

The first stage of the calibration process is to calculate the radial leg pattern (expressed as a spline function) by a process of inverse solution from the zero wind transect, recognising that the transect is simply the integral or summation of the sprinkler pattern in the direction parallel to the travel direction.

Applied depths were collected for a gun set at a 360º sector angle and machine speed of 30m/hr with a near zero wind speed of 0.68 m/s and direction 264º to the travel direction. The depth values each side of the machine for each distance were averaged to produce the zero wind transect as seen in Figure 1. The resulting radial leg application rates are shown in Figure 2.

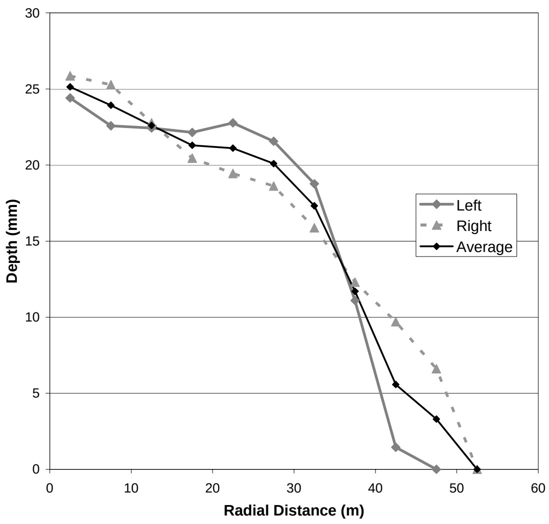

Figure 1 Measured zero wind transect

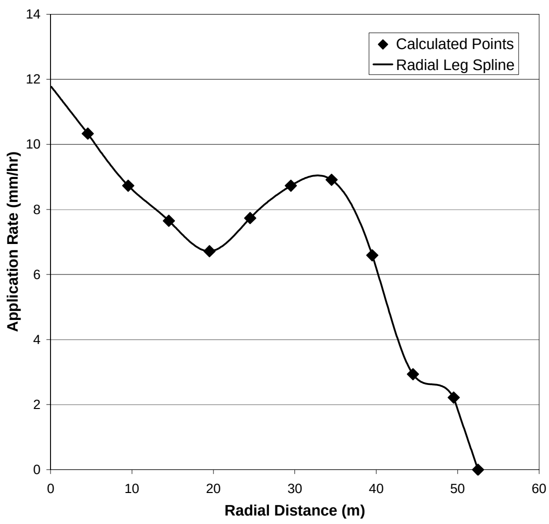

Figure 2 Calculated radial leg

The normal procedure for measuring the applied depths does not allow a depth measurement in the middle of the travel lane, therefore the application rate anywhere between the zero radial distance and the distance to the first measurement (Figure 2) must be estimated. In this example it was assumed that the application rate varies linearly between these points at a slope equal to that between the first and second points. The reproduction of the measured transect from the radial leg pattern is shown in Figure 3.

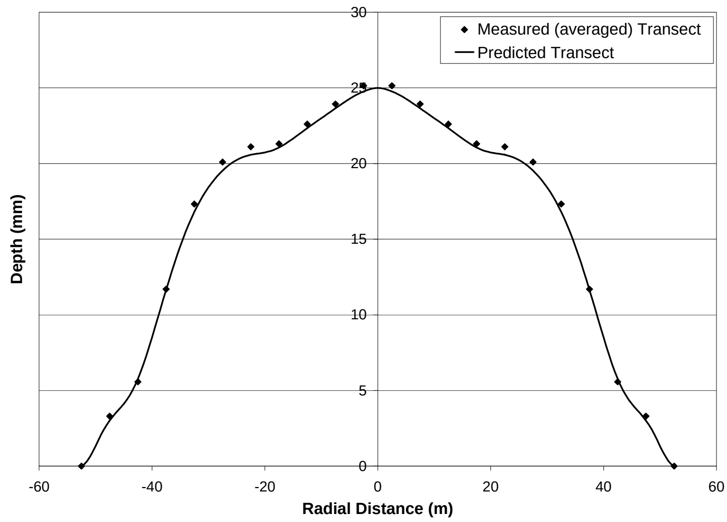

Figure 3 Fit of the zero wind transect

Calibration of the Wind Drift and Range Shortening Parameters – an Example

Several transects were collected under a range of different wind conditions with the same gun configuration as used in the determination of the radial leg. These transects were collected using a closer catch-can spacing (1.667m) than that used to collect the zero wind data. Two wind affected transects were chosen from this data with moderate wind speeds and different wind directions: in transect 1 the wind is approximately parallel to the travel direction at 3.97 m/s and 344º while for transect 2 it is nearly perpendicular at 2.52 m/s at 84º. Nozzle sector angles were 284º for both transects.

TRAVGUN optimised the six wind parameters simultaneously from the two transects with a total RMSE of 3.770. The resulting predicted transects shown in Figures 4 and 5 provide an adequate fit to the measured data for both transects and indicate good prediction of both the range shortening and wind drift. The individual RMSE for transects 1 and 2 were 2.463 and 2.854, respectively. The equivalent zero wind pattern (for 284º sector angle) is also shown in these figures.

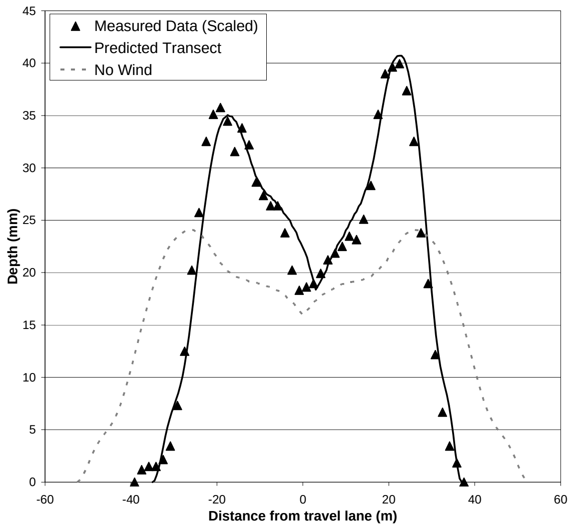

Figure 4 Fit of the model to transect 1

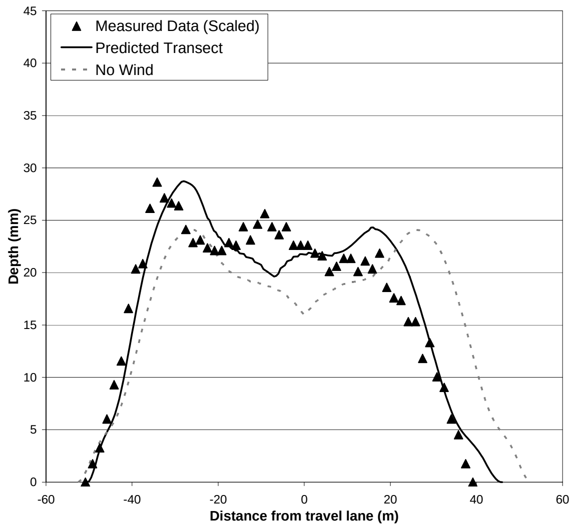

Figure 5 Fit of the model to transect 2

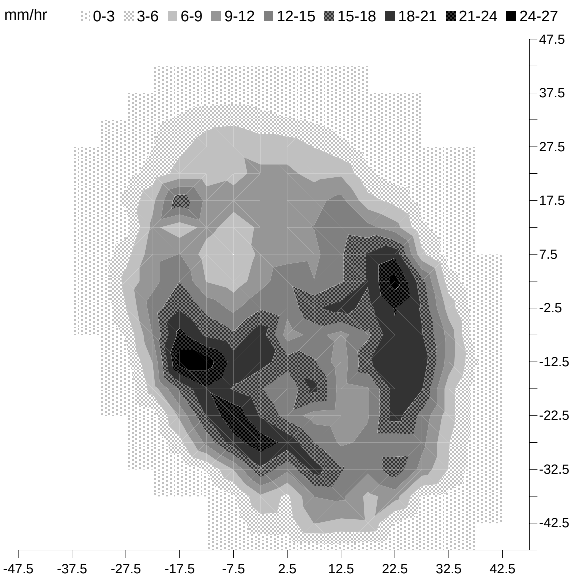

Figure 6 Measured spray pattern

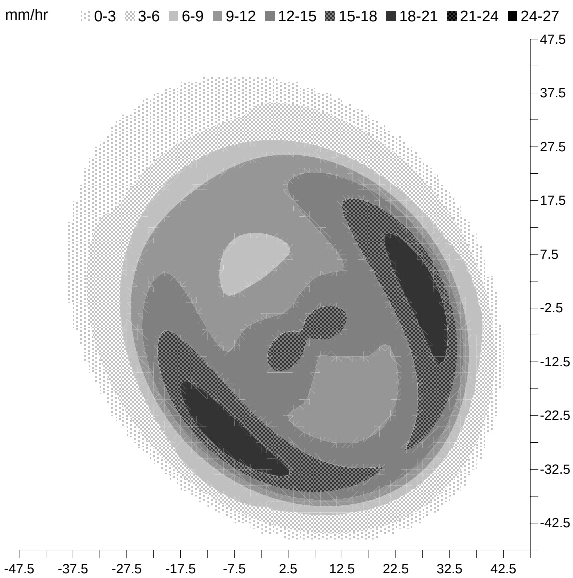

Figure 7 Predicted spray pattern

The quality of the prediction can also be illustrated by the ability of the model to predict measured sprinkler patterns. Several stationary sprinkler patterns for the same gun were collected on a 5 m grid over a range of wind speeds from 0.68 to 3.66 m/s, with the pattern chosen for this paper collected under a wind speed of 3.58 m/s at 324º (Figure 6). The TRAVGUN simulation of this sprinkler pattern is presented in Figure 7.

Features of the TRAVGUN model

The TRAVGUN model is a decision support model to assist irrigators and extension staff to select nozzle type, size, wetted sector angle and lane spacing that will give high application uniformities and minimum loss of water through deep percolation and irrigation of noncropped areas. It allows analyses to be performed at two levels: (i) a single irrigation event, and (ii) the whole season.

For a single irrigation event with known wind speed and direction, the TRAVGUN results include: the depths applied by adjacent passes of the machine and the uniformity of applications across the width of the field. Uniformity over the entire field is determined from the depths of irrigation applied within the cropped area bounded by adjacent travel lanes and the ends of the field. The volume of water: (i) lost as deep percolation, and (ii) applied outside of the cropped area is used as an indicator of application efficiency.

Over a full irrigation season a machine will operate in a variety of wind conditions (speeds and directions). The effective uniformity of applications over that season will differ from and usually be greater than those for the individual irrigations. The model uses wind data, typical of the local area during the irrigation season, to predict the seasonal field uniformity for a range of values of sector angle, lane spacing, and travel direction. The seasonal wind pattern is described by a simplified wind rose having 25 combinations of wind speed and direction, consisting of 8 wind directions (from the eight point compass), each of which has three wind speed ranges (0-5 km/h, 5-10 km/h, 10-15 km/h), plus a zero wind condition. Applied depths are calculated for each combination of wind speed and direction (including the zero wind case). These are then weighted, according to the likelihood of occurrence of that wind event, and summed together to give the predicted seasonal uniformity.

Acknowledgements

The data used in this paper was kindly provided by Tim Lacey, Cranfield University.

References

Al-Naeem, M.A.H., 1993. Optimisation of Hosereel Rain Gun Irrigation Systems in Wind; Simulation of the Effect of Trajectory Angle, Sector Angle, Sector Position and Lane Spacing on Water Distribution and Crop Yield. PhD Dissertation, Silsoe College, Cranfield University.

Augier, P., 1996. Contribution à l'étude et à la modélisation mécaniste statistique de la distribution spatiale des apports d'eau sous un canon d'irrigation: Application à la caractérisation des effets du vent sur l'uniformité d'arrosage. Thése de doctorat de l'ENGREF.

Grose, D.J., 1999. Mathematical Modelling and Simulation of Irrigation Sprinklers. *PhD Dissertation*, Silsoe College, Cranfield University.

Richards, P.J. and Weatherhead, E.K., 1993. Prediction of raingun application patterns in windy conditions. J Agric Engng Res 54, 281-291.

Smith, R.J., Baillie, C.P. and Gordon G., 2002. Performance of travelling gun irrigation machines. Proc Australian Society of Sugar Cane Technologists 24, 235-240.