A Decision Support Model for Travelling Gun Irrigation Machines

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Abstract

The computer model, TRAVGUN was developed to simulate the irrigation applications by travelling gun machines under different wind conditions. A novel approach to calibration of the model was introduced to give both the sprinkler pattern (radial leg) and the six wind parameters of the empirical sprinkler irrigation model, from simple field measurements of applied depths along transects perpendicular to the travel direction of the machine. Once calibrated, TRAVGUN can be used to investigate the sprinkler patterns and transects under other wind conditions. When seasonal wind information is available the user can simulate the field application while changing various operating parameters such as the lane spacing and sector angle to identify the optimum values for those parameters.

Keywords

rain gun; sprinkler pattern; radial leg; wind distortion

Notation

A, B, C	wind drift constants for a particular gun setting
D, E, F	range shortening constants for a particular gun setting
D_k	seasonal depth (mm) applied at a point summed over all probable wind conditions
M_{AW}, M_{UW}, M_{DW}	sprinkler pattern radius across wind, upwind and downwind, respectively
R_m	maximum wetted radius (m) under zero wind conditions
R_S	factor describing the range shortening of the sprinkler pattern due to wind
S	sine of the three-dimensional angle between the direction of the water jet and the wind direction
W	wind speed (m s^{-1})
W_D	factor describing the drift of the sprinkler pattern due to wind
X, Y	co-ordinates for points in the sprinkler pattern
d_i	applied depth measurements (mm) taken along transects perpendicular to the travel direction of the machine at distances x_i from the centre line of the travel lane
w_1 and w_2	spline fitting factors

z(r)	the time averaged application rate (mm h^{-1}) at the radial distance *r* (m) from the gun
z_1 and z_2	application rates (mm h^{-1}) at r_1 and r_2, respectively
z_w	application rate in wind affected conditions at X_W, Y_W
z_0	application rate in zero wind conditions at X_{WS}, Y_{WS}
α	trajectory angle of the nozzle
ϕ	horizontal angle between the wind direction and direction of jet
δr	difference between r_1 and r_2 (m)
θ	sector angle in degrees

1. Introduction

Travelling gun irrigation is the most popular form of irrigation in the Queensland dairy industry, and is also common within the Queensland sugar and horticultural industries. Although few new machines are currently being purchased, short boom machines now being preferred, travelling guns will continue to play a significant role in these industries for the foreseeable future.

High uniformity of irrigation applications is essential to the efficient production of high yields from these irrigated crops. However, poor uniformity of applications is characteristic of travelling gun machines under commercial conditions, as supported by recent field measurements. For example, Smith *et al.* (2002) reported that only 25% of machines tested in sugar cane in the Bundaberg area of Queensland gave uniformities greater than the recommended Christiansen Coefficient of Uniformity (CU) of 80%. Similarly, Wigginton and Raine (2001) obtained Distribution Uniformity (DU) values from eight travelling guns in the Mary Valley ranging from 1 to 88%, with an average of 62%. Only two of the eight travellers tested had a DU equal to or above the benchmark value of 80%.

There are a variety of reasons for this poor performance, including excessive spacing between travel lanes, poor nozzle selection, sub-optimal gun sector angle, and the operation of machines in windy conditions. Despite these problems, very little work has been undertaken to develop and disseminate strategies to tackle these issues.

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 an accurate simulation of sprinkler distribution patterns is the prediction of the impact of wind on the pattern. In general, wind lengthens the sprinkler distribution pattern downwind, shortens the distribution pattern upwind and narrows the distribution pattern normal to the wind direction (Shull and Dylla, 1976). Travelling gun machines tend to be operated with less overlap of adjacent sprinkler patterns than other sprinkler systems. Hence wind will have a greater effect on performance.

In this paper a model (TRAVGUN) is described that employs an empirical description of the wind distorted sprinkler pattern to predict the pattern of applications from a travelling gun machine. This is coupled with historic wind data for the region to show the probable annual or seasonal performance of the machine. The model allows for varying nozzle size and type, operating pressure, sector angle, and lane spacing. Calibration of the model for a particular machine is undertaken by a novel procedure using field-measured transects of depths applied, under no wind and moderate wind conditions.

2. 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 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 the 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. The aim of this model was to use laboratory measurements of droplet size distributions to eliminate the need for the large database of sprinkler pattern data for different conditions (pressures, wind speeds and wind directions) required by the empirical model (NIWASAVE, 1999). The two phases in the plume consisted of a main-jet phase, which included air entrainment, and a phase of individual droplets.

Similarly, Grose *et al*. (1998) and 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 (NIWASAVE, 1999).

Both the ballistic and empirical methods have been shown to produce adequate results after calibration. The empirical method requires a substantial amount of sprinkler pattern 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 outside the budget for most researchers. Indeed, Grose (1999) conceded that the empirical model produced acceptable results, removing the need to collect droplet size distribution data.

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.

3. 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). The model as applied is described below.

The primary data required by the model are the application rates along a radius from the gun (a radial leg pattern), determined in zero wind conditions. In order to reduce model computations, Richards and Weatherhead (1993) used a 3rd order polynomial to describe the radial leg. The fitting of this curve is also relatively simple. However the 3rd order polynomial always results in a sharp rise in the application rate close to the gun, an area where measurements are often not obtained because of a need to keep catch cans clear of the travel path of the machine.

TRAVGUN uses a cubic spline to describe the radial leg sprinkler pattern, where the application rate at any distance from the stationary gun can be described by:

$$z(r) = \frac{360}{\theta}\left(\frac{(r-r_1)^3}{6\delta r}w_2 + \frac{(r_2-r)^3}{6\delta r}w_1 + \left(\frac{z_2}{\delta r} - \frac{w_2\delta r}{6}\right)(r-r_1) + \left(\frac{z_1}{\delta r} - \frac{w_1\delta r}{6}\right)(r_2-r)\right) \quad (1)$$

where $z(r)$ is the time averaged application rate (mm h^{-1}) at the radial distance r from the gun (m), with r lying between the distances r_1 and r_2;
z_1 and z_2 are the application rates (mm h^{-1}) at r_1 and r_2, respectively;
δr is the difference between r_1 and r_2 (m);
w_1 and w_2 are spline fitting factors; and
θ is the sector angle in degrees.

Varying the wetted sector angle of the gun varies the average application rate over the wetted area by the ratio between the sector angle and a full circle rotation (360^o), with the full circle rotation producing the minimum application rate.

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:

$$W_D = \left[A + B\left(\frac{r}{R_m}\right) + C\left(\frac{r}{R_m}\right)^2\right]W \quad (2)$$

$$R_S = \left[D\left(\frac{r}{R_m}\right) + E\left(\frac{r}{R_m}\right)^2 + F\left(\frac{r}{R_m}\right)^3\right]WS \quad (3)$$

where A, B, C are the wind drift constants for the particular gun setting;
D, E, F are the range shortening constants for the gun setting;
R_m is the maximum wetted radius under zero wind conditions;
W is the wind speed (m s^{-1}); and
S is the sine of the three-dimensional angle between the direction of the water jet and the wind direction and is given by:

$$S = \sqrt{\sin^2(\alpha)\cos^2(\phi) + \sin^2(\phi)} \quad (4)$$

α is the trajectory angle of the nozzle; and
ϕ is the horizontal angle between the wind direction and direction of jet.

The change in the wetted radius, perpendicular to the wind direction and upwind and downwind of the gun, constrains the values of the constants A to F. The equations describing this change in the sprinkler pattern radius across wind (M_{AW}), upwind (M_{UW}) and downwind (M_{DW}) are:

$$M_{AW} = (D + E + F)W \quad (5)$$

$$M_{UW} = (D + E + F)W \sin(\alpha) + (A + B + C)W \quad (6)$$

$$M_{DW} = (D + E + F)W \sin(\alpha) - (A + B + C)W \quad (7)$$

The location of any point in the wind-affected pattern (X_W, Y_W) is found by moving the point from its position in the zero-wind pattern (X_{WS}, Y_{WS}) through the effect of wind drift and range shortening. The location of X_W is only affected by range shortening, however the relocation of Y_W is dependent on both wind drift and range shortening. Determination of these new points is shown in Eqs. 8 and 9:

$$X_w = X_{ws} - R_S \sin(\theta) \quad (8)$$

$$Y_w = Y_{ws} - W_D - R_S \cos(\theta) \quad (9)$$

Finally, the application rate (I_W) at the relocated points X_W, Y_W can be calculated from:

$$z_w = \frac{z_0}{\frac{\partial X_w}{\partial X_{ws}} \frac{\partial Y_w}{\partial Y_{ws}}} \quad (10)$$

where z_w is the application rate in wind affected conditions at X_W, Y_W;
z_0 is the application rate in zero wind conditions at X_{WS}, Y_{WS} (Eq. 1); and
$\frac{\partial X_w}{\partial X_{ws}}, \frac{\partial Y_w}{\partial Y_{ws}}$ are the partial derivatives of Eqs. 8 and 9 (Al-Naeem, 1993).

4. Calibration

4.1 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. There is also a compromise required between the grid size used in the tests and the precision achieved. Al-Naeem (1993) collected data on a relatively wide 8m by 8m grid, resulting in 196 depth measurements for a typical big gun with a maximum throw radius of 52m. In this case a substantial amount of interpolation is required between the depth measurements.

A novel approach is proposed 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, height and trajectory angle. A minimum of three sets of applied depths, measured along transects orientated perpendicular to the travel path of the machine, one of which must be obtained in quiescent conditions. The other transects may be collected at any moderate wind speed or 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 to determine the radial leg sprinkler pattern and secondly to estimate the values of the wind drift and range shortening parameters.

4.2 Inverse Solution to Determine the Radial Leg from a Measured Transect

The first stage of the calibration process is to calculate the radial leg pattern from the transect of applied depths measured in quiescent conditions. The lateral transect of applied depths is simply the integral or summation of the sprinkler pattern in the direction parallel to the travel direction. This consists of depth measurements d_i taken at a series of lateral distances x_i from the travel path starting at the outer extent of the wetted area and finishing as close as practically possible to the machine. There is no specific requirement for these measurements but it advised that they should be spaced closely and approximately equidistant. Similarly the sprinkler pattern is envisaged as a series of concentric circles of radius r_i having the application rate z_i and whose spacing corresponds to the spacing of the depth measurements.

For the first non-zero measurement, the application rate will vary from zero when the outside radius of the spray pattern reaches that point to a maximum value when the machine is aligned with the transect and then will reduce back to zero as the machine moves away (see Fig. 1). The distance travelled by the machine in the time it is contributing to the water depth d_1 is given by:

$$l_1 = 2\sqrt{r_0^2 - r_1^2} \tag{11}$$

The average application rate for the line l_1 is given by:

$$\overline{z_1} = d_1 V / l_1 \tag{12}$$

where V is the machine speed. This application rate $\overline{z_1}$ is deemed to occur at a radial distance from the nozzle equal to the distance to the centroid of the area A_1 (Fig. 1).

The depth d_2 consists of two components, a summation of the applications at the known rate $\overline{z_1}$ for a given duration and a second period of time at the unknown rate of $\overline{z_2}$. By the same logic as used to calculate $\overline{z_1}$, the average application rate for l_2 is:

$$\overline{z_2} = \left(d_2 - \frac{2\left(\sqrt{r_0^2 - r_2^2} - \sqrt{r_1^2 - r_2^2}\right)\overline{z_1}}{V} \right) \frac{V}{2\sqrt{r_1^2 - r_2^2}} \tag{13}$$

Again this is deemed to occur at a radial distance equal to the centroid of the area A_2.

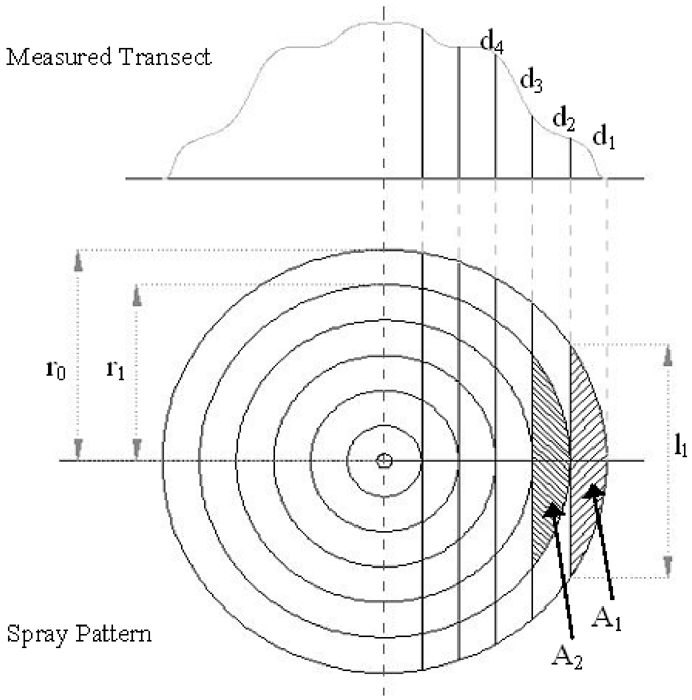

Figure 1 – Procedure for determining the radial leg pattern from the measured transect

Progressively, and by the same process, the average application rate for each radial distance is determined. The final step in the process is to fit the cubic spline (Eq. 1) to the computed application rates and radii.

The process is further complicated where the machine is operating at a sector angle less than 360° and further still where the sectoring is not symmetrically aligned about the travel direction. In these cases the areas are split up into regular shapes to facilitate the above calculations.

4.3 Radial Leg from Measured Transect – an Example

Applied depths were collected for a gun set at a 360º sector angle and machine speed of 30 m h^{-1} with a near zero wind speed of 0.68 m s^{-1} and wind direction 264º to the travel direction. The depth values were averaged between the two sides for each distance to produce the zero wind transect as seen in Fig. 2. The process described in section 4.2 was used to arrive at the radial leg application rates and the consequent spline function (Fig. 3).

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 (Fig. 3) must be estimated. In this example it was assumed that the application varies linearly between these points at a slope equal to that between the first and second points.

The zero wind transect reproduced from the estimated radial leg pattern is shown in Fig. 4.

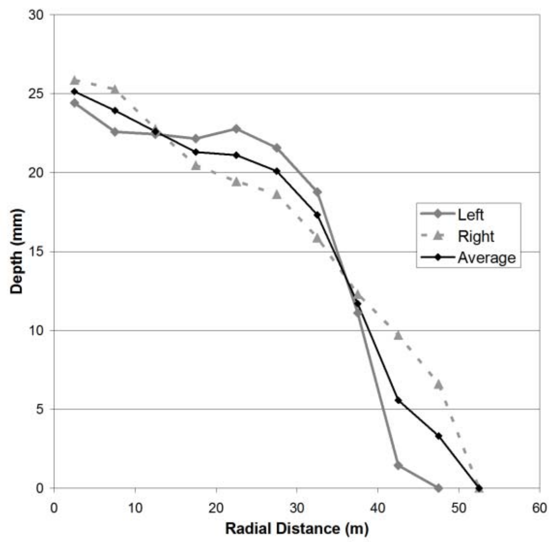

Figure 2 - Measured zero wind transect

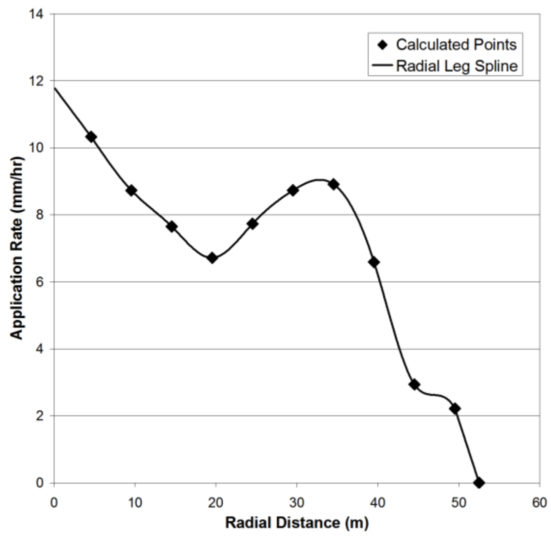

Figure 3 - Calculated radial leg

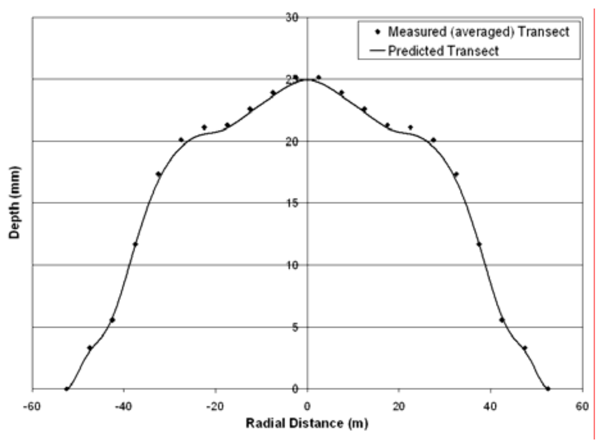

Figure 4 - Fit of the zero wind transect

4.4 Calibration of the Wind Drift and Range Shortening Parameters

Although it is possible to perform the calibration with any number of wind affected transects, it is recommended that at least two transects representing different wind conditions are used. Prior to the calibration process the measured wind affected transects are scaled to ensure that they have the same average application rate as that used to calculate the radial leg. The routine aims to minimise the difference, expressed as an average root mean square error (RMSE), between the measured and predicted transects, using a simple gradient search method. The expression for the RMSE for an individual transect is:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(M_i - P_i\right)^2}{n}} \qquad (14)$$

where M and P are the measured and predicted depths, respectively, and n is the number of depth measurements in the relevant transect.

The six wind parameters are given starting values; then an initial search routine assesses values for each between -10 and +10 to ensure the best starting point for the remainder of the process. During software development it was observed that the parameters are somewhat interdependent within the two groups *A*, *B*, *C* and *D*, *E*, *F*. A similar issue was encountered in the development of the inverse procedure to estimate the parameters of the modified Kostiakov infiltration equation from surface irrigation advance and runoff measurements (Gillies and Smith 2005). The same optimisation routine as used by Gillies and Smith (2005) is applied here. First the parameters are incremented individually until the error between measured and predicted data points cannot be reduced any further. Following this, the parameters are incremented in the same direction but as a group until once again the error cannot be reduced further. To overcome problems with convergence the group step size increases each time the individual parameter search is executed. When both the individual and group searches do not reduce the RMSE the step sizes of the parameters are reduced by half and the process is repeated.

For the example in the following section the steps sizes of the six parameters start at the initial value of 1 and undergo a total of 12 reductions. Additional reductions in the step size will continue to decrease the RMSE but the improvement in the fit does not justify the added computation time.

4.5 *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 to produce the measurements used in the calibration of the radial leg. These transects were collected using a closer catch-can spacing (1.667 m) than that used to collect the zero wind data. Two wind affected transects with moderate wind speeds and different wind directions were chosen for this example. In transect 1 the wind is approximately parallel to the travel direction at 3.97 m s^{-1} and 344º while for transect 2 it is nearly perpendicular at 2.52 m s^{-1} at 84º. Nozzle sector angles were 284º for both transects.

TRAVGUN optimised the six wind parameters simultaneously from the two transects, with an average RMSE of 2.622 mm. The resulting transects shown in Figs. 5 and 6 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 2.204 and 3.041 mm, respectively. The equivalent zero-wind pattern for this machine (for a 284º sector angle) is also shown in these figures.

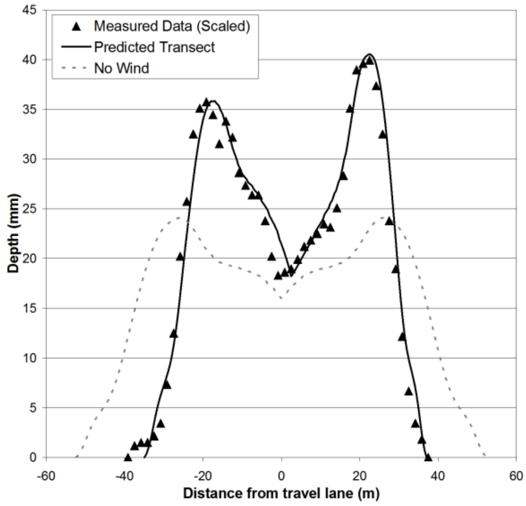

Figure 5 – Fit of the model to wind transect 1

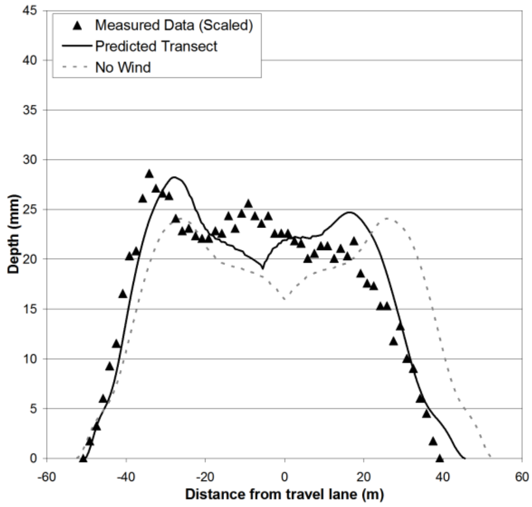

Figure 6 – Fit of the model to transect 2

The quality of the prediction can also be illustrated by the ability of the model to predict measured sprinkler patterns. Several stationary sprinkler patterns were also collected for the same gun on a 5 m grid over a range of wind speeds from 0.68 to 3.66 m s^{-1}. Two such sprinkler patterns (not used in the preceding calibration) have been chosen for this paper. Pattern 1 (Fig. 7) resulted from a wind speed of 2.16 m s^{-1} at 14 degrees and for pattern 2 (Fig. 9) the wind speed was 3.58 m s^{-1} at 324 degrees. The TRAVGUN simulations of these sprinkler patterns using the calibration described previously are presented in Figs. 8 and 10. The RMSE between the non-zero measured grid points and the corresponding points in the measured spray pattern was calculated as 2.805 and 3.4483 mm h^{-1} for patterns 1 and 2, respectively.

5. Features of the TRAVGUN Decision Support Model

The TRAVGUN model is intended as a decision support model to assist irrigators and extension staff in the selection of nozzle types, sizes, wetted sector angles and lane spacings that will give high application uniformities and minimum loss of water through deep percolation and irrigation of non-cropped areas. It is a stand alone software package written in C++ with a graphical user interface.

Data required for the model are the field measured transects required for the model calibration, and machine specific data of travel speed and trajectory angle. Wind data may be either: a particular wind speed and direction, a list of wind conditions with corresponding probabilities, or a seasonal wind rose.

The TRAVGUN model allows analysis to be performed at three levels, the sprinkler pattern, a single irrigation event, and the whole season.

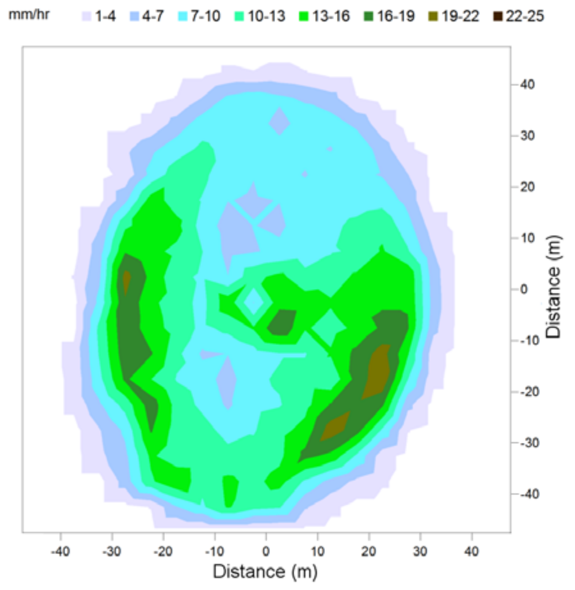

Figure 7 – Measured spray pattern 1 (2.16 m/s)

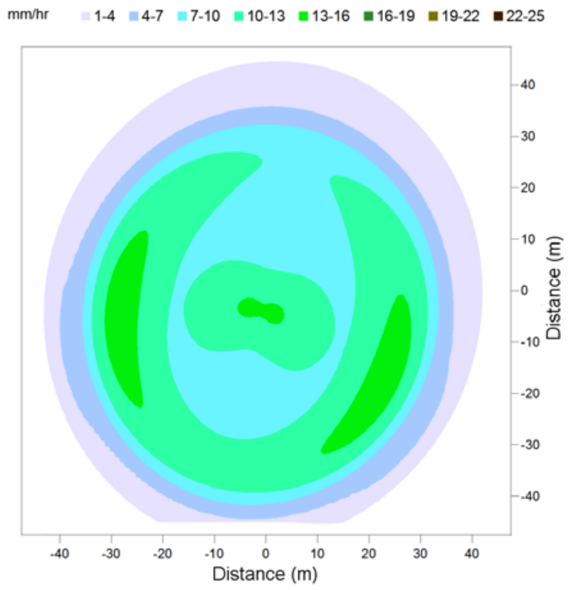

Figure 8 – Predicted spray pattern 1 (2.16 m/s)

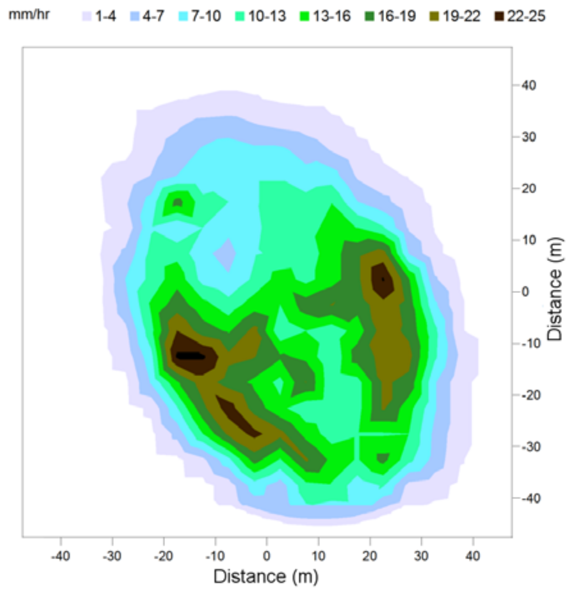

Figure 9 – Measured spray pattern 2 (3.58 m/s)

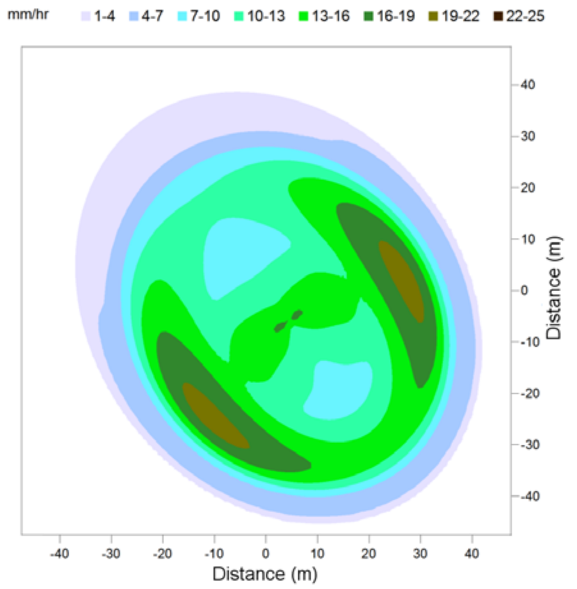

Figure 10 – Predicted spray pattern 2 (3.58 m/s)

5.1 Single Irrigation Event

For a single irrigation event with known machine settings and known wind speed and direction, TRAVGUN calculates:

- 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 map of the applied depths in the area between two adjacent travel lanes and the ends of the field (for example, Fig. 11),
- a cumulative distribution curve of applied depths in this area, and
- the uniformity of applied depths over the field.

This gives the user a graphic view of the irrigation performance for that irrigation, particularly the adequacy of the lane spacing.

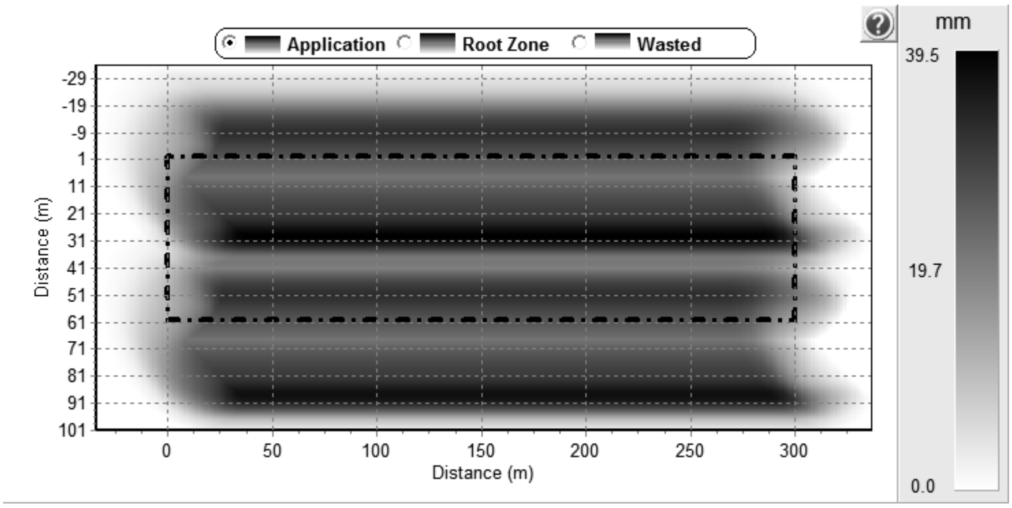

Figure 11 - Simulation of the applied depths between two travel lanes

Operators of travelling gun machines use various tactics to improve the uniformity of applications at the end of the field. These include irrigating with the machine stationary for a period at the start and/or finish of a run (termed delay in this model), and starting and finishing a run at some distance (in or out) from the end of the cropped area (termed offset). These tactics necessarily involve a trade off between uniformity and application efficiency. Attempts to more uniformly water the entire cropped area inevitably result in a greater volume of water being applied (lost) outside the cropped area and vice versa. Different irrigators will have different preferences hence TRAVGUN allows the user to simulate the effect on uniformity and application efficiency of machine delay and machine offset along the run. In the model a negative offset value indicates the distance in field from the edge of the irrigated area (therefore the negative offset direction at the start of the run is opposite to the negative offset direction at the end of the run.

Uniformity 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 lost as deep percolation, and applied outside of the cropped area is used as the indicator of application efficiency. It is not a true estimate of application efficiency because no attempt is made to calculate the water lost to direct evaporation from the droplets during flight or by interception on the crop canopy.

5.2 Seasonal Uniformity

Over a full irrigation season a machine irrigating a particular field 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 (Grose, 1999). Grose also showed that the increase in uniformity was directly related with lane spacing. However, for single irrigation events followed by only one subsequent event, uniformities do not necessarily increase (Grose, 1999).

The model allows the use of wind conditions, typical of the local area during the irrigation season, to calculate the seasonal irrigation uniformity while changing any of the nozzle or field design parameters such as sector angle, lane spacing and travel direction. By this means machine settings can be selected to give the best performance for a given lane spacing and 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^{-1}, 5-10 km h^{-1}, 10-15 km h^{-1}), plus a zero wind speed condition. The data required is the proportion of time for which each condition applies. Overhead irrigation should not be undertaken when wind speeds exceed 15 km h^{-1}, hence this wind speed category is not included in the seasonal uniformity analysis. TRAVGUN assumes that the wind speed values within each range can be represented by the mid-point of the range, for example, winds in the range 10-15 km h^{-1} will be taken as 12.5 km h^{-1}. Alternatively, the seasonal wind pattern can be supplied simply as a list of wind speeds and directions with the probability of occurrence of each.

Once the user selects the two design parameters for analysis, applied depth grids (covering the area between adjacent travel lanes and the ends of the field) 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 create a predicted "seasonal field application":

$$D_k = \sum_{j=1}^{n} p_j d_{jk} \qquad (16)$$

where D_k is the seasonal depth (mm) at point k for all wind conditions,
p_j is the frequency of occurrence of the wind speed and direction combination,
d_{jk} is the individual depth (mm) at point k for wind condition j, and
n is the number of separate wind conditions (n = 25 when using the wind rose).

The seasonal uniformity is then calculated using the seasonal depths. This process is repeated for every combination of the selected design parameters. The example in Figure 12 was created using the gun calibration performed in section 4, with a full wind rose and for lane spacings ranging from 40 to 80 m and sector angles between 180° and 360°.

6. Further Development of the Model

Initial evaluation of the calibration technique has identified a number of areas that require further development. Firstly, the procedure used to calculate the radial leg pattern from the applied depth transect collected under quiescent conditions is particularly sensitive to small errors in the individual measured depths, that is, to the small irregularities usually found in measured depth transects. Because of the sequential nature of this procedure these small irregularities are magnified in the radial leg. Smoothing of the measured data has proved to be beneficial. Some further work is required to establish the preferred smoothing technique. Secondly, the values of the six wind parameters change depending on the individual transects chosen for the calibration. It has also been observed that the parameters are not entirely independent. Consequently different combinations of parameter values can give similar predictions of wind affected sprinkler patterns. Further work is required to establish the true nature of the parameter dependency and to provide guidance on the number of transects required for a stable calibration and on the selection of the wind affected transects, for example, based on wind speed and direction or data quality.

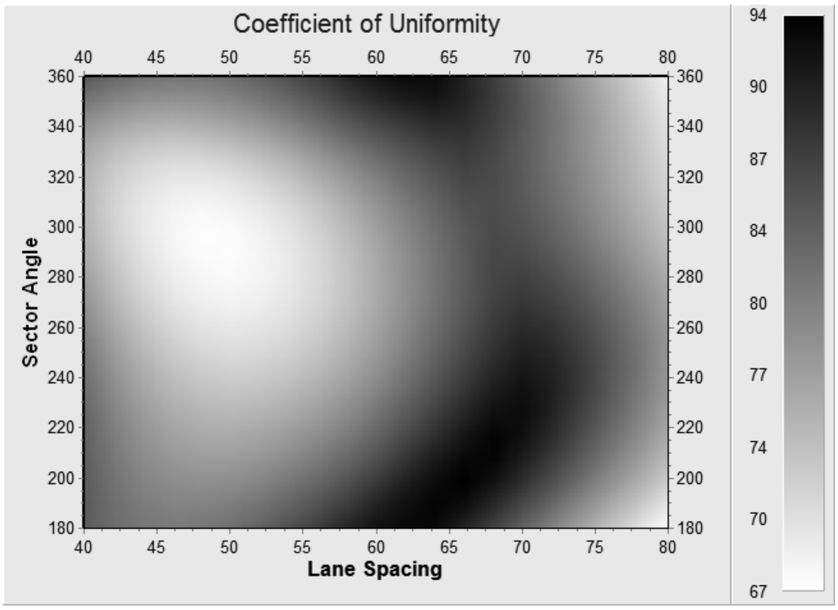

Figure 12 - Optimising the seasonal performance by changing the lane spacing and sector angle. Seasonal uniformity of applications is indicated by the colour scale

7. Conclusions

An empirical model to predict the depths of irrigation applied by travelling gun machines has been developed. The calibration procedure is unique in that both the radial leg pattern and the six parameters that describe the distortion of the sprinkler pattern due to wind can be determined using a minimum of three depth transects, perpendicular to the travel lane, measured during normal operation of the machine. Following calibration the simulation model can be used to investigate the sprinkler patterns and field uniformity under any moderate wind speed. TRAVGUN has been developed as a practical tool for irrigation extension staff for the evaluation and design of travelling gun irrigation systems.

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