1 **CHARACTERIZING MICROTOPOGRAPHICAL EFFECTS ON**
2 **LEVEL-BASIN IRRIGATION PERFORMANCE**

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Abstract

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Microtopography has long been recognized as one of the key variables in level-basin irrigation performance, although little effort has been devoted to establish its relevance. In this work, experimental data are used to quantify the influence of microtopography on irrigation performance. An irrigation evaluation was performed on a small level-basin (256 m²) LASER levelled to zero slope. Irrigation depth was gravimetrically measured and estimated at the 49 nodes of a regular network. Data from the irrigation evaluation and a two-dimensional flat-bed model were used to estimate irrigation depth. Irrigation times, soil surface elevation and distance to the inlet were estimated at the same nodes, and a correlation matrix was computed. Results showed that soil surface elevation was highly and significantly correlated with the times of advance (0.725^{***}), recession (-0.815^{***}) and opportunity (-0.852^{***}), and with the measured irrigation depth (-0.583^{***}). Distribution uniformity using soil water measurements was 71.0%. Estimates from the irrigation evaluation and the two-dimensional model were 85.3% and 94.9%, respectively. The irrigation evaluation procedure could explain 30^{***}% of the measured variability in irrigation depth. A large

1 part of the unexplained variance in measured irrigation depth
2 seems to be due to the spatial variation of infiltration
3 properties. Predictions by the two-dimensional model were not
4 significantly related to the measured values. A simple method was
5 devised to estimate microtopography-adjusted irrigation
6 performance from the results of a flat bed model and the standard
7 deviation of elevation. Microtopography can have an important
8 effect on level-basin irrigation performance. Models not
9 considering this variable may incur large errors when simulating
10 irrigation performance.

11

1 **Introduction**

2 Although the definition of level-basin irrigation implies
3 land levelling to zero slope (Hart et al., 1980), even after
4 precision levelling the undulations of the soil surface can have
5 an important effect on the advance and recession processes of an
6 irrigation event (Walker and Skogerboe, 1987). The pattern of
7 undulations embedded into a flat topography will be referred to
8 as microtopography. In the last decades, generalized use of LASER
9 guided land levelling has significantly improved the performance
10 of level-basin irrigation systems. Use of this equipment produces
11 much more uniform levelling as compared to traditional means
12 (Erie and Dedrick, 1979). Evidence has proven that this in turn
13 results in faster advance, higher irrigation uniformity, and
14 better potential application efficiency.

15 The relevance of water application variability in irrigated
16 agriculture has long been recognized. Bucks and Hunsaker (1987)
17 stated that the scarcity of field-scale information on the
18 effects of water application uniformity and soil variability is
19 a serious limitation to the optimum design and management of
20 irrigation systems. Different authors have succeeded in
21 establishing relationships between irrigation nonuniformity and
22 spatial variability in crop evapotranspiration or yield (Russo,
23 1984; Bucks and Hunsaker, 1987; Jaynes and Hunsaker, 1989; Or and
24 Hanks, 1992). The source of variability in these works was
25 associated with the nonuniformity induced by the irrigation
26 application system and the variability of infiltration and other
27 soil physical properties.

1 Clemmens (1988) identified three factors which can affect
2 irrigation uniformity in a level basin: variations in opportunity
3 time, variations in surface retention of water, and variations
4 in infiltration properties. Microtopography increases the
5 variability in opportunity time (delaying the advance process)
6 and is responsible for the variability in surface retention
7 (resulting in wide variations in recession time). The effects of
8 microtopography on irrigation uniformity can be fully revealed
9 by an irrigation evaluation if provisions are made to record the
10 advance and, particularly, recession processes in detail.

11 Bautista and Wallender (1985) and Jaynes and Hunsaker (1989)
12 analyzed the effect of spatially varied infiltration on
13 irrigation performance. Their results justify implementation of
14 this variability in surface irrigation simulation models.
15 Successful attempts have been reported by Wallender (1986) and
16 Bali and Wallender (1987) for furrow irrigation, and by Jaynes
17 and Clemmens (1986) for border irrigation.

18 Spatial variation of surface elevation has received less
19 attention. Bucks and Hunsaker (1987), in their study on water use
20 variability in level-basins, characterized the levelling status
21 of the analyzed irrigation units. Due to the field layout, LASER
22 levelling was more effective in large basins than in small ones,
23 reducing the value of the standard deviation of surface
24 elevation. When irrigated with the same discharge, irrigation
25 uniformity was consistently higher in the large basins. The
26 authors concluded that variations in land elevation were more
27 important to irrigation uniformity than differences in basin

1 size. Clemmens (1988) presented a method to analyze the effect
2 of several causes of irrigation nonuniformity, including
3 microtopography. The proposed method uses a statistical approach
4 to combine the effects of selected sources of variability.

5 Level-basin irrigation simulation models can be classified
6 as one- and two-dimensional. One-dimensional models consider
7 only one spatial independent variable, and are based on the
8 hypothesis that there is no variation in flow depth and discharge
9 across the level-basin. Two-dimensional models consider two
10 spatial coordinates and are more accurate than one-dimensional
11 models in cases involving point inlets or irregular field
12 geometries (Playán et al., 1994b). Level-basin irrigation models
13 developed to date consider that the field is perfectly levelled.
14 Disregarding microtopography in level-basin irrigation
15 modelling can result in unrealistic, high estimates of irrigation
16 uniformity and efficiency.

17 In this article, results are presented from an irrigation
18 evaluation performed in a square level-basin with an area of only
19 256 m². Small scale irrigation units can permit much more intense
20 and accurate characterization of the variables involved in an
21 irrigation event. Spatial variability of soil surface elevation
22 and soil water content, key issues in this research, can be much
23 better addressed if observations are available at the nodes of
24 a fine network. Such level of detail would be unaffordable in
25 regularly sized level-basins. Although the level-basin was LASER
26 levelled, use of a small inflow discharge (with associated small
27 flow depth) resulted in an irrigation event that was strongly

1 governed by the residual microtopography, thus reproducing the
2 response of a poorly graded field. The possible extrapolation of
3 the results to real scale irrigated level-basins is discussed.

4

1 **Materials and methods**

2 A large field was LASER levelled to zero slope, ripped and
3 then rolled to smoothen the soil surface. A small square plot of
4 16 x 16 m was marked inside this field and an earth ditch was built
5 along its contour to create the small level-basin object of this
6 experimental work. In the upcoming maps of the experimental plot
7 the origin of the x and y coordinates is located at the southwest
8 corner of the level-basin.

9 Spatial variability was analyzed using geostatistical
10 techniques (Clark, 1979). This approach is based on computation
11 of the semivariance, a statistical function of the distance that
12 separates two points. The experimental semivariogram is a plot
13 of semivariance versus distance. Theoretical semivariograms are
14 functions used to model experimental data. These functions are
15 based on three parameters: nugget, sill, and range. The nugget
16 is the value of the semivariogram for a distance equal to zero.
17 A nonzero nugget can be interpreted as an indication of a
18 systematic measurement error or the existence of spatial
19 variation at a smaller scale than measured. The final, stable
20 value of the semivariogram equals the sum of sill and nugget. The
21 range is the distance at which the semivariance reaches its stable
22 value. It indicates the distance over which measurements are
23 correlated, thus identifying the size of the different soil
24 units. The parameters of the theoretical semivariogram were
25 statistically validated by cross-validation (Samper and Carrera,
26 1990). The kriging procedure was used to interpolate the values
27 of the variable at untested locations.

1 A precision soil survey was performed to characterize soil
2 surface elevation. A radiometric total station was used to
3 determine the x , y , and z coordinates of an irregular network
4 composed of 108 points of the level-basin. The mean elevation was
5 subtracted from each observation to transform elevation data into
6 deviations from mean level. Kriging was used to estimate surface
7 elevation at the 49 nodes of a regular network starting at the
8 point with coordinates $x = 1.1$ m; $y = 1.1$ m, and with nodes spaced
9 2.3 m in both directions.

10 Soil water was gravimetrically determined before and after
11 the irrigation event. A Veihmeyer type auger (2 cm internal
12 diameter, 1.20 m effective depth) was used for soil sampling. At
13 each time, samples were collected in a 0.5 m radius of each node
14 of the regular network. Separation between sampling points for
15 a given node before and after the irrigation event was provided
16 to prevent interference from the first auger hole (acting as a
17 preferential water channel) in the second sampling. For
18 additional safety the field was ripped and rolled after the first
19 sampling.

20 Soil water content before and after the irrigation event at
21 the exact location of the 49 nodes was estimated using kriging.
22 Use of a destructive procedure to measure soil water requires an
23 offset between successive samples and, as a consequence,
24 interpolation must be used to estimate nodal soil water. The fact
25 that there is always a sampling point in the vicinity of each node
26 prevents large interpolation errors, since most of the
27 contribution to a nodal value is due to the neighbouring sample.

Interpolation errors could be significant in the presence of sharp gradients in soil water, like those created by discontinuities in soil physical properties.

A water turnout was located at the origin of coordinates, and water inflow was maintained constant throughout the irrigation event. A volumetric water measurement device was used to estimate discharge and total irrigation volume.

The irrigation evaluation was performed following the procedures described by Merriam and Keller (1978). Particular attention was paid to the determination of the location of the advance and recession fronts. At fixed time intervals (15 min for advance and 60 min for recession) the location of the front was recorded in situ with the help of coloured flags. The total station was later used to determine the coordinates of the marked points, which were used to draw maps. The advance, recession, and opportunity times corresponding to the nodes of the grid were estimated using these maps.

Two automated infiltrometer cylinders were used to estimate the coefficients of a Kostiaikov infiltration equation:

$$Z = k \tau^a \quad (1)$$

where Z is the cumulative infiltration (m), τ is the opportunity time (min), and k and a are empirical coefficients. The cylinders were 0.4 m in diameter, and were located outside the level-basin, adjacent to two of its opposite sides. A circular ditch with a diameter of 2 m was built around them to avoid boundary effects. The adjusted infiltration approach (Walker and Skogerboe, 1987) was used to improve the significance of the infiltration

coefficients. Using this technique, the value of k was adjusted so that the sum of the infiltration depths computed with the 49 observed opportunity times equalled the depth of water added to the plot.

While numerous parameters of irrigation performance have been devised and applied (Willardson, 1959), only two of them will be used in this work, following descriptions by Merriam and Keller (1978). The Distribution Uniformity (DU) index can be expressed as:

$$\text{;Error!} \quad (2)$$

where Z_{25} is the average depth infiltrated in the lowest one quarter of the area (mm), and Z_{avg} is the average depth of water infiltrated (mm). The potential application efficiency of the low quarter (PELQ) follows the expression:

$$\text{;Error!} \quad (3)$$

where ZS_{25} is the average depth stored in the root zone when the average depth infiltrated in the lowest quarter of the area equals the soil water depletion (mm).

The irrigation of rectangular level-basins from one of its corners was successfully simulated by Playán et al. (1994a), who presented a two dimensional model suited for irregular level-basin geometries and multiple inflow points. The model uses an explicit leapfrog finite difference scheme to solve the two-dimensional shallow water equations for the initial and boundary conditions that characterize level-basin irrigation.

1 Soil surface slope terms are set to zero in the model, therefore
2 assuming a flat geometry. The model is used in this work to
3 simulate the irrigation event and estimate the magnitude of the
4 error associated with the use of flat bed models in situations
5 where microtopography can play an important role.

6

Results and discussion

The survey of soil surface elevation indicated that the plot had no significant slope, although in 5% of the measured points surface elevation differed more than 2 cm from the mean. The standard deviation of soil surface elevation was 0.92 cm. These results are in agreement with previous findings by Bucks and Hunsaker (1987) who reported an average standard deviation of 1.07 cm as characteristic of large LASER levelled basins.

The experimental semivariogram corresponding to surface elevation is presented in figure 1. A spherical theoretical semivariogram was fitted to experimental data and cross-validated. The parameters corresponding to this semivariogram are presented in table 1. The zero value of the nugget suggests that the survey revealed all the variability present in the plot. It can also be concluded that the average size of the soil surface undulations is 6 m.

The theoretical semivariogram was used to estimate soil surface elevation at the 49 nodes of the regular network. Figure 2 is a contour line map of surface elevation deviation from the mean. The figure reveals the existence of three high spots with relative elevations greater than 1.5 cm, and three low spots with relative elevations less than 1.5 cm.

The plot was irrigated with a constant discharge of 2.12 l/s for 155.5 min. The corresponding irrigation application depth was 77.3 mm. A very low discharge was applied to the plot in order to ensure a relatively slow advance. In this way, the lack of uniformity induced by the advance can be compared to that of

1 regularly sized level-basins, and the results of this work will
2 be more readily extrapolated. It has to be noted, though, that
3 the flow depth associated to such a small discharge is much
4 smaller than usual level-basin flow depths. This in turn results
5 in a very shallow overland flow whose advance is seriously limited
6 by tiny soil surface undulations. This is why the advance process
7 reported in this small LASER levelled experimental basin is
8 representative of poorly graded level-basins in which advance can
9 only be completed at the expense of applying large irrigation
10 depths.

11 Soil water measurements before and after the irrigation
12 event were analyzed using geostatistical techniques. Soil water
13 recharge due to irrigation was computed as the difference between
14 both soil water contents at the nodes of the regular network.
15 Table 1 summarizes the parameters of the theoretical
16 semivariograms corresponding to the three variables, and figure
17 3 is a plot of the experimental and theoretical semivariograms.
18 Soil water before irrigation is characterized by a gaussian
19 semivariogram, while both soil water after irrigation and soil
20 water recharge follow spherical models. Irrigation increased the
21 semivariance of soil water content at short distances (under 8
22 m), and decreased large scale semivariance. The theoretical
23 semivariogram for soil water recharge is characterized by a zero
24 nugget, indicating the adequacy of the fineness of the sampling
25 network, and a 10 m range, smaller than the range corresponding
26 to soil water contents before and after the irrigation event (23
27 m and 15 m, respectively). Figure 4 is a contour line plot of

1 measured soil water recharge. Circles indicate the location of
2 the nodes of the regular network.

3 Variability in soil water content before irrigation seems
4 to be due to soil physical properties, since the field had not
5 been irrigated for years. Soil properties such as texture can have
6 a large effect on soil water content. This is evidenced by the
7 fact that, subjected to the same conditions, sandy soils
8 equilibrate at much lower water contents than clay soils.

9 The validity of soil water measurements might be limited by
10 three uncontrolled sources of error. Evaporation from the soil
11 surface might be significant, though measurements were made
12 shortly after the irrigation event. Deep percolation beyond 1.20
13 m might have happened locally, although the lower end of the soil
14 cores collected after the irrigation event was dry. Finally,
15 horizontal redistribution of water could have had an appreciable
16 effect on the variability of irrigation depth.

17 The irrigation evaluation allows estimation of soil water
18 recharge at the same 49 locations based on a combination of
19 opportunity times and an infiltration equation. A Kostiaikov
20 infiltration equation was fitted to the results of the two ring
21 infiltrometer tests. The value of R^2 corresponding to each ring
22 was 96% and 99%, indicating adequacy of the Kostiaikov equation
23 to model infiltration in this particular soil. When regression
24 was run for data corresponding to the two rings, an R^2 of 76.2%
25 was found. The values of the resulting parameters where: $k =$
26 0.0165 m/min^a , and $a = 0.230$. Characterization of the spatial
27 variability of infiltration was not attempted because of the

interference of the large number of required point measurements with the evaluation process. Jaynes and Hunsaker (1989) identified a range value for spatial correlation of cumulative infiltrated depth lower than 3.8 m, which suggests the need to use a very fine sampling network. The existence of this variability is nonetheless revealed by the differences between the two infiltration measurements, which for an opportunity time of two hours show values of 42.8 and 56.4 mm, respectively.

Figure 5 is a plot of the locations of the advancing front at 15 min intervals during the irrigation event. Advance was not complete, leaving zones of the three previously identified high spots uncovered (1.7% of the total plot area). Figure 6 is a plot of the location of the recession front at 1 hour intervals, starting at the time of cutoff. Both figures were used to estimate the opportunity time at the 49 nodes, and resulting times were used to adjust the k coefficient, yielding the following infiltration equation:

$$Z = 0.0222 \tau^{0.230} \quad (4)$$

Equation 4 was used to estimate nodal values of soil water recharge. A contour line plot of this variable (that will be denoted as evaluated recharge) is presented in figure 7. In this plot areas not reached by the advance process are shaded.

Application of the two-dimensional model to the irrigation event yields a new estimate of soil water recharge that will be referred to as simulated recharge. A 289-node square computational grid was used to represent the plot for simulation purposes. Equation 4 was used to model the infiltration process,

1 and a Manning n of 0.04 was estimated as characteristic of
2 smoothly tilled soils. Figure 8 is a plot of the location of the
3 advancing front at 15 min time intervals. Figure 9 is a contour
4 line plot of simulated soil water recharge, evidencing a somehow
5 cylindrically symmetrical pattern in which recharge at a point
6 is inversely related to its distance to the inflow.

7 Table 2 presents some basic statistics of soil water
8 recharge resulting from measurement, evaluation, and simulation.
9 The average values are very similar for all three procedures:
10 76.5, 77.3, and 76.3 mm, respectively. Agreement between average
11 measured and evaluated irrigation depth is an indication of the
12 adequacy of the soil water measuring procedures. Measured values
13 show a coefficient of variation of 25.6%, similar to the 18.8%
14 reported by Jaynes and Hunsaker (1989) as an average of four
15 neutron probe monitored level-basin irrigation events. This
16 coefficient is reduced to 10.0% in the evaluation and to only 3.7%
17 in the simulation. Reduced variability is a result of the
18 simplifications adopted by the two estimation methods. None of
19 them considers spatial variability of infiltration and other
20 physical properties, and simulation does not take
21 microtopography into account either.

22 Table 3 summarizes the results of the three procedures. The
23 time of advance observed in the field experiment was 155.5 min,
24 and accounted only for advance to the 98.3% of the area. The
25 simulated time of advance was of 118.0 min. As for the time of
26 recession, an observed value of 410.0 min should be compared to
27 a simulated value of 264.8 min. Figure 10 is a plot of the advance

and recession trajectories for the evaluation and the simulation. The figure reveals a slower advance phase in the evaluation, and a sloping recession phase due to the effect of field microtopography, which is neglected by the model. The time of recession corresponding to 50% of the area can be computed using evaluation data, yielding a value of 306.7 min, much closer to the estimate provided by the simulation model.

Uniformity and efficiency indexes are also presented in table 3. The reduced variability in soil water recharge in the evaluation and simulation procedures results in overestimation of irrigation performance. The PELQ was 69.76% for the measured recharge, 84.93% for the evaluated recharge, and 94.69% for the simulated recharge.

To further investigate the relationship between all the involved factors, a correlation matrix was computed for the 49 nodal observations of the following variables: Time of advance, recession, and opportunity (resulting from the irrigation evaluation), soil surface elevation, distance to the inlet, soil water content before and after irrigation, and soil water recharge as measured, evaluated and simulated. Table 4 presents the results of this analysis in a matrix format. The upper half of the matrix contains the correlation coefficients with an indication of their significance level, while the lower part of the matrix contains the corresponding P-values.

The first indication of the effect of microtopography in this irrigation event is the high and strongly significant negative correlation (-0.652^{***}) between the time of advance and

the time of recession. Points last reached by the advancing front are the first to recede. This is confirmed by the strong positive correlation between time of advance and elevation (0.725^{***}), and by the strong negative correlation between the time of recession and elevation (-0.815^{***}).

Traditional analyses of surface irrigation relate time of advance to distance to the inlet. When those two variables are faced, a large, positive correlation is found (0.620^{***}). Both surface elevation and distance to the inlet (in this order) account for large parts of the variability in the time of advance, while the time of recession can only be explained on the accounts of surface elevation. The difference between time of recession and time of advance (opportunity time) yields a negative, highly significant correlation with surface elevation (-0.852^{***}), but it is not correlated with the distance to the inlet.

The highly significant correlation coefficient between soil water before and after the irrigation event (0.785^{***}) indicates a trend in parts of the field to remain consistently drier or wetter than the average of the plot. This tendency can not be explained by microtopography since both variables are uncorrelated with surface elevation. Jaynes and Hunsaker (1989) obtained similar results and attributed them to the spatial variability of soil texture or bulk density, both related to the water holding capacity of the soil.

Measured recharge shows high and significant correlations with the times of advance, recession and opportunity, and with surface elevation (-0.583^{***}). Both the soil water before and after

1 the irrigation event show a negative, high and strongly
2 significant correlation with distance to the inlet. This seems
3 to reflect a cylindrically symmetrical gradient in soil physical
4 properties stemming from the location of the irrigation inlet.
5 The difference between both soil water contents (measured
6 recharge) is not significantly correlated with distance.

7 Evaluated recharge is very highly correlated with all three
8 characteristic times, as was to be expected. Correlation between
9 evaluated recharge and surface elevation is negative, very high
10 and significant (-0.850^{***}), while the correlation with distance
11 to the inlet is slightly significant (-0.296^*).

12 Simulated recharge is correlated with the time of advance
13 (-0.664^{***}), and with the opportunity time (0.392^{**}), but shows no
14 correlation with the time of recession, since surface elevation
15 is not implemented in the model and simulated recession occurs
16 simultaneously at all nodes. Simulated recharge is not
17 significantly correlated with surface elevation, but shows a very
18 strong correlation with distance to the inlet (0.966^{***}).

19 It has to be noted that in the transition from measured to
20 simulated recharge, surface elevation loses all significance
21 and, at the same time, distance to the inlet becomes the key
22 variable. Evaluated recharge represents an intermediate state in
23 which both variables are relevant.

24 Correlation between measured and evaluated recharge is
25 highly significant (0.584^{***}). Analysis of the corresponding
26 linear regression model (with an R^2 of 34.2%) revealed that the

intercept was not significantly different from zero. The zero-intercept linear regression resulted in:

$$y = 0.995 x \quad R^2 = 30.4^{***} \% \quad (5)$$

where estimated recharge is the independent variable and measured recharge is the dependant variable.

According to this regression model, the evaluation procedure can only explain 30.4% of the variability found in soil water recharge. Figure 11 is a plot of the 49 points and the regression line. The standard error in the estimation of the measured recharge is 16.3 mm. Correlation between measured and simulated recharge was not significant, implying that the model was unable to explain the soil water recharge produced by the irrigation event.

The small percentage of the measured variability in irrigation depth explained by the irrigation evaluation suggests that spatial variability of infiltration may be responsible of a large amount of the measured variability. These results are in agreement with the previous work by Clemmens (1988), who found that (for a hypothetical case study) spatial variability of opportunity time and surface storage could explain 34.6% of the variance in irrigation depth. The spatial variability of infiltration properties explained 31.6% of the variance.

In the analyzed irrigation event, use of an advanced two-dimensional simulation model has proven to have no use in the explanation of the variability found in soil water recharge. If the model was upgraded with a surface elevation module able to reproduce accurately the advance and recession front

1 configurations, the results could match the significance of the
2 evaluated data. Combination of the spatial variability of surface
3 elevation and infiltration could extend the agreement between
4 simulated and measured recharge beyond the limits found in this
5 research. This would only be done at the expense of very intense
6 field determinations and computations.

7 Results of this work can only be directly extrapolated to
8 poorly graded level-basins. In a regularly sized LASER levelled
9 basin the advance phase would show much better agreement with the
10 advance trajectory simulated with a flat-bed model (Playán et
11 al., 1994a). The discrepancies would therefore be concentrated
12 on the recession curve.

13 It has long been recognized that, in most types of surface
14 irrigation, recession measurement is a very subjective task
15 (Merriam and Keller, 1978). Field observations of time of
16 recession in level-basins are probably located somewhere between
17 the time of 50% recession and the time of complete recession.
18 Considering that the typical extent of undulations in a LASER
19 levelled basin is in the order of 6 m, detailed observation of
20 recession in a full sized level-basin would be completely
21 unmanageable. The correlation found in this work between soil
22 surface elevation and recession time (-0.815^{***}) is not affected
23 by the change in scale and should be characteristic of most LASER
24 levelled basin irrigation events. Discrepancies between
25 evaluated and simulated soil water recharge in full sized LASER
26 levelled basins will be reduced, but still important. This can
27 be illustrated by the fact that, even in the reported case in which

1 advance was slowed and distorted by the strong influence of
2 microtopography, nonuniformity induced by recession was about
3 164% larger than that induced by the advance process.

4 Practical applications of this research focus on the
5 obtention of microtopography-adjusted estimates of uniformity
6 and efficiency. These estimates could be based on predictions by
7 a flat-bed simulation model and a microtopography index, such as
8 the standard deviation of elevation. In the proposed case study,
9 elevation data was successfully tested to fit a normal
10 distribution with mean 0.00 mm and standard deviation of 9.20 mm.
11 Twenty sets of random deviates following this distribution were
12 generated and added to the flat-bed model estimates of nodal
13 irrigation depth to account for microtopography induced surface
14 retention. Distribution uniformity was computed for the twenty
15 sets of data, yielding an average DU of 85.13%, very similar to
16 the value obtained from the irrigation evaluation (85.30%). This
17 is a simple method and has obvious practical implications related
18 to level-basin irrigation design and evaluation. Its major
19 theoretical weakness is that it does not include the effects of
20 microtopography on the advance phase of the irrigation event. On
21 the other hand, as shown in figure 10, microtopographical effects
22 on advance are of small magnitude when compared with the effects
23 on recession.

1 **Conclusions**

2 The analysis of the experimental irrigation event reveals
3 that microtopography can play a major role in the performance of
4 level-basin irrigation systems. LASER guided land levelling
5 results in improved uniformity and efficiency, but the residual
6 undulations of the soil surface can still induce large
7 variability in the advance and recession processes. Proper design
8 of the irrigation units can minimize the effect of
9 microtopography on the advancing front by using a large inflow
10 discharge. This will in turn result in large overland flow depths
11 which will make residual microtopography irrelevant to the
12 advance process. On the contrary, the recession phase will always
13 be governed by differences in surface elevation. By the time of
14 recession, surface undulations will have produced similar
15 (inverted) undulations in soil water recharge.

16 The effect of microtopography on level-basin irrigation
17 performance could be further analyzed with the help of
18 two-dimensional level-basin simulation models implementing
19 spatially varied surface bed elevation. Predictions of
20 irrigation performance based on such models should be lower and
21 closer to experimental measurements. Nevertheless, more
22 simplified approaches can be used to estimate
23 microtopography-adjusted irrigation performance without going
24 through intense surface elevation data collection and analysis.
25 In this sense, the standard deviation of surface elevation is an
26 adequate parameter to be used in a corrector algorithm aimed to
27 yield microtopography-adjusted

1 DU and PELQ based on estimates obtained with flat-bed simulation
2 models.

3 Combined use of surface elevation and infiltration variability
4 in level-basin irrigation evaluation and modelling could result
5 in much more accurate estimates of spatial variability of soil
6 water recharge due to irrigation.

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References

- Bali, K., Wallender, W. W., 1987. "Water application under varying soil and intake opportunity time". Trans. ASAE, 30(2):442-448.
- Bautista, E., Wallender, W. W. 1985, "Spatial variability of infiltration in furrows", Trans. ASAE, 28(6):1846-1851.
- Bucks, D. A., Hunsaker, D. J., 1987. "Water use variability in irrigated level-basins", Trans. ASAE, 30(4):1090-1098.
- Clark, I. 1979. Practical Geostatistics. Applied Science Publishers Ltd., Barking, Essex. 129 pp.
- Clemmens, A. J., 1988. "Method for analyzing field scale surface irrigation uniformity". ASCE J. Irrig. Drain. Div., 114(IR1):74-88.
- Erie, L. J., Dedrick, A. 1979. "Level basin irrigation: a method for conserving water and labor". Farmers' Bulletin, USDA.
- Hart W. E., Collins H. G., Woodward G., Humpherys A. S., 1980. "Design and operation of gravity or surface systems". Design and operation of farm irrigation systems. ASAE Monograph number 3, pp. 501-582.
- Jaynes, D. B., Clemmens, A. J., 1986. Accounting for spatially variable infiltration in border irrigation models. Water Res. Research, 22(8):1257-1262.
- Jaynes, D. B., Hunsaker, D. J., 1989. "Spatial and temporal variability of water content and infiltration on a flood irrigated field". Trans. ASAE, 32(4):1229-1238.

- 1 Merriam J. L., Keller J., 1978. "Farm irrigation system
2 evaluation: a guide for management". 3rd. ed., Utah State
3 University, Logan, Utah, 285 pp.
- 4 Or, D., Hanks, R. J., 1992. "Soil water and crop yield spatial
5 variability induced by irrigation nonuniformity". Soil Sci.
6 Soc. Am. J., 56:226-233.
- 7 Playán, E., Walker, W. R., Merkley, G. P. 1994a. "Two-dimensional
8 simulation of basin irrigation. I: Theory", ASCE J. Irrig.
9 Drain. Div., 120(5):837-856.
- 10 Playán, E., Walker, W. R., Merkley, G. P. 1994b. "Two-dimensional
11 simulation of basin irrigation. II: Applications", ASCE J.
12 Irrig. Drain. Div., 120(5):857-870.
- 13 Russo, D., 1984. "Statistical analysis of crop yield-soil water
14 relationships in heterogeneous soil under trickle
15 irrigation". Soil Sci. Soc. Am. J., 48:1402-1410.
- 16 Samper, F. J., Carrera, J. 1990. Geoestadística: aplicaciones a
17 la hidrología subterránea. Centro Internacional de Métodos
18 Numéricos en Ingeniería. Barcelona. 484 pp.
- 19 Walker, W. R., Skogerboe, G. V., 1987. Surface Irrigation, theory
20 and practice. Prentice-Hall, Inc., Englewood Cliffs, New
21 Jersey. 386 pp.
- 22 Wallender, W. W., 1986. Furrow model with spatially varying
23 infiltration. Trans. ASAE, 29(4):1012-1016.
- 24 Willardson, L. S., 1959. "Characterizing water use by means of
25 efficiency concepts", American Society of Agricultural
26 Engineers annual meeting, Paper No. 59-204.

Tables

Table 1. Parameters of the theoretical semivariograms for surface elevation, soil water before and after irrigation and soil water recharge.

Variable	Units	Type	Nugget	Sill	Range
Soil surface elevation	cm	Spherical	0.0	1.62	6.0
Soil water before irrigation	mm	Gaussian	100	3000	23
Soil water after irrigation	mm	Spherical	50	1400	15
Soil water recharge	mm	Spherical	0.0	450	10

Table 2. Comparison of statistics for soil water recharge as measured gravimetrically and estimated by irrigation evaluation and simulation (based on the 49-node network).

Recharge	Average (mm)	Maximum (mm)	Minimum (mm)	SD (mm)	CV (%)
Measurement	76.5	124.4	37.0	19.6	25.6
Evaluation	77.3	87.0	62.0	7.72	10.0
Simulation	76.3	80.1	70.3	2.8	3.7

Table 3. Main results of the irrigation event as measured, evaluated and simulated.

	Advance time (min)	Recession time (min)	DU (%)	PELQ (%)
Measurement	-	-	70.97	69.76
Evaluation	155.5 ⁽¹⁾	410.0	85.30	84.93
Simulation	118.0	264.8	94.85	94.69

(1) Advance was not complete

Table 4. Correlation matrix between the main irrigation variables estimated at the 49 nodes (Upper half part: correlations and levels of significance; lower half part: P values).

	EVALUATION			SURVEYING VARS.		SOIL WATER		RECHARGE		
	Advance Time	Recession Time	Opport. Time	Elevation	Distance	Soil Water Before	Soil Water After	Measured Recharge	Evaluated Recharge	Simulated Recharge
Advance Time		-0.652 ^{***}	-0.883 ^{***}	0.725 ^{***}	0.620 ^{***}	-0.300 [*]	0.648 ^{***}	-0.485 ^{***}	-0.901 ^{***}	-0.664 ^{***}
Recession Time	0.000		0.932 ^{***}	-0.815 ^{***}	0.023 ^{ns}	-0.233 ^{ns}	0.159 ^{ns}	0.600 ^{***}	0.904 ^{***}	0.119 ^{ns}
Opport. Time	0.000	0.000		-0.852 ^{***}	-0.279 ^{ns}	-0.001 ^{ns}	0.409 ^{**}	0.604 ^{***}	0.991 ^{***}	0.392 ^{**}
Elevation	0.000	0.000	0.000		0.023 ^{ns}	0.055 ^{ns}	-0.337 [*]	-0.583 ^{***}	-0.850 ^{***}	-0.129 ^{ns}
Distance	0.000	0.844	0.052	0.874		-0.578 ^{***}	-0.612 ^{***}	-0.006 ^{ns}	-0.296 [*]	-0.962 ^{***}
Soil Water Before	0.037	0.107	0.992	0.705	0.000		0.785 ^{***}	-0.411 [*]	0.032 ^{ns}	0.518 ^{***}
Soil Water After	0.000	0.275	0.004	0.018	0.000	0.000		0.242 ^{ns}	0.431 ^{**}	0.624 ^{***}
Measured Recharge	0.000	0.000	0.000	0.000	0.970	0.033	0.094		0.584 ^{***}	0.107 ^{ns}
Evaluated Recharge	0.000	0.000	0.000	0.000	0.039	0.827	0.002	0.000		0.401 ^{**}
Simulated Recharge	0.000	0.415	0.005	0.379	0.000	0.000	0.000	0.465	0.004	

Figure captions

- 1.Experimental (symbols) and theoretical (line) semivariogram for soil surface elevation.
- 2.Contour line map of soil surface elevation (cm).
- 3.Experimental (symbols) and theoretical (lines) semivariograms for soil water content before and after the irrigation event (to a depth of 1.20 m) and for recharge due to irrigation.
- 4.Contour line map of soil water recharge (mm) due to irrigation.
- 5.Location of the advancing front at 15 min time intervals.
- 6.Location of the recession front at 60 min time intervals. Time 0 is the time of cut off.
- 7.Contour line map of soil water recharge (mm) as estimated by the irrigation evaluation. Circles indicate the location of the nodes of the 49-node network. Areas not covered by the advance process are shaded.
- 8.Location of the simulated advancing front at 15 min intervals.
- 9.Contour line map of simulated soil water recharge (mm).
- 10.Advance-recession diagram for the evaluation and simulation.
- 11.Measured soil water recharge versus estimations by irrigation evaluation and simulation model.

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