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Design and management guidelines for contour basin irrigation layouts in southeast Australia

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Abstract

Contour basin irrigation layouts are used in Australia for sequential cultivation of rice and other crops on soils with low infiltration rates. Multiple interconnected basins through gates installed in the check banks and backflow at the inlet end are unique features of contour basin layouts used in southeast Australia. Design and management guidelines were developed using a two-dimensional computer simulation model (COBASIM) for contour basin layouts. The computer model was used to simulate and analyse the performance of single- and multiple-basin layouts in response to key design variables including aspect ratio, inflow rates, microtopography, vertical interval between basins and number of interconnecting drainage outlets. The main aim of this study was to provide designers and practitioners with an overall view of the likely impact trends arising from variations in key design factors and to improve design practices. Irrigation performance was measured by the time of advance needed to cover the entire basin area, application efficiency, water requirement efficiency and distribution uniformity. The study revealed that the aspect ratio and local microtopography have a significant impact on the performance in these layouts. A mild slope in the advance direction can improve performance when a small depth of irrigation is required, while there are no significant benefits from increasing the elevation difference between adjacent basins.

Keywords: Contour basin irrigation layouts; Design and management guidelines

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1. Introduction

Contour basin irrigation layouts are used in Australia for cultivation of rice on soils with low infiltration rates and where water may need to be ponded for long periods of time. The check banks of the basin are erected across the slope following the contour of the land. These banks are constructed by borrowing the soil from the outside edges of the bank area resulting in a toe-furrow which serves as supply as well as drainage channel for the basin. Water supply channels are constructed down slope in order to provide command for direct supply to each basin. These basins are characterised by drain-back drainage. Water is allowed to fill the basin from the supply channel and upon completion of irrigation, drainage runoff is allowed into the next downstream basin. Water enters and ponds in the first basin until it is completely inundated. The supply is then cut-off from the first basin and diverted towards the second basin. While water is supplied to the second basin, the surplus water from the first basin is also allowed to drain into the second basin through gaps in the check bank as well as back to the supply channel. The process is repeated until all the basins in the irrigation block are irrigated. Drainage runoff from the bottom basin is usually diverted into farm storage for reuse. Normally 5–10 basins of different sizes are included in an irrigation block. A typical water flow pattern during the inflow and advance and recession and drainage in contour basin layouts is shown in Fig. 1a and b.

These traditional layouts are inefficient when used with crops other than rice. Inefficiencies arise from poor drainage that leads to groundwater accessions, waterlogging, and

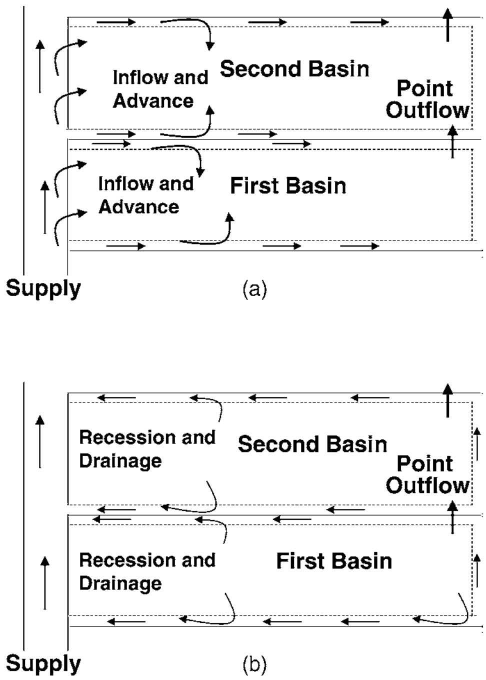

Fig. 1. Water flow patterns in contour basin layouts during: (a) inflow and advance; (b) recession and drainage.

poor production. The problem of poor drainage also occurs with rice cultivation when basins must be drained in late season prior to harvest. The same contour layouts cannot be used effectively for irrigating both rice and other crops in sequence, thus the choices and management options available to farmers are restricted.

Since rice is commonly grown in these layouts on soils with low infiltration rates, it is vital to introduce management flexibility that enables farmers to grow other crops on the same layouts. It is possible to use these layouts for rice and cereals and pastures if they are properly designed and managed. This is critically important to obtain better returns by providing additional management flexibility. However, existing practices for design and management of these layouts are guided only by experience and intuitive understanding which preclude farmers from achieving the desired level of flexibility in their cropping pattern.

Design and management of existing layouts is difficult without the ability to simulate overland water flow and infiltration. At present there are no standard design and management criteria available for basin layouts. The existing practice is primarily confined to a topographic design with no evaluation of the consequences of the design on the hydraulic performance of these basins. This often results in unnecessary expenditure by the farmers on land forming and infrastructure with little efficiency improvement. Overseas criteria and experience are not directly applicable to these layouts as basin irrigation systems used in other countries usually consist of single hydraulically independent closed basins.

2. Simulation model for contour basin irrigation layouts

A two-dimensional simulation model titled ''contour basin simulation model'' (COBASIM) was developed to simulate the overland flow hydraulics and infiltration processes that occur in contour basin layouts (Khanna et al., 2003a,b). The model's governing equations are based on a zero-inertia approximation to the two-dimensional shallow water equations of motion. The equations of motion are transformed into a single non-linear advection–diffusion equation in which the friction force is described by Manning's formula. The empirical Kostiakov equation (Clemmens et al., 1981; Playan et al., 1994a,b; Singh and Bhallamudi, 1997) and the quasi-analytical Parlange equation (Parlange et al., 1982; Edenhofer and Schmitz, 1985; Schmitz et al., 1985; Haverkamp et al., 1990; Singh, 1996) are used to model the infiltration process.

The model is capable of simulating contour basin layouts of regular and irregular shape and size. It simulates inflow from the supply channel, and in multiple-basin systems, it also simulates runoff into the downstream basin through the basin check banks and backflow into the supply channel. The main objective of developing a simulation tool was to enable designers and practitioners to simulate the behaviour of multiple design scenarios. This requires the application of the model for each design case using the specific geometric configuration and design data for the system concerned.

Field trials were also conducted on actual commercial fields with the objective of understanding the hydraulic behaviour, assessing irrigation performance and collecting data for validation of the computer model. Monitoring of these layouts was carried out over two irrigation seasons between 1998 and 2000. In each season, two irrigation events were monitored. In the 1998–1999 season, the first irrigation and second irrigation of the season were monitored within a 2-week interval. During the irrigation season 1999–2000, monitoring was extended to multiple basins. The parameters monitored during all the irrigation events were inflow, outflow, depth of overland flow, advance and recession of waterfront, pre- and post-irrigation soil moisture status and evaporation (Khanna, 2001).

In this paper, the computer model COBASIM is used to explore in general the effect of the main design parameters on the performance of contour basins. The main aim of this analysis is to provide designers and practitioners with an overview of the likely impact trends arising from changes to these design factors. This analysis, however, is only intended to provide practitioners with a general understanding and sensitivity of each design parameters and their effect on irrigation performance. For design purpose, the model must be used with the specific geometric and soil parameters of the design site in order to carry out a simulation analysis to select the preferred design option.

3. Simulation experiments

3.1. Simulation strategy

Several parameters were selected for the evaluation of design and management guidelines for contour basins. These include:

- aspect ratio, i.e. ratio of width to length of the basin;
- longitudinal slope;
- inflow rates;
- local microtopography;
- elevation difference between basins (contour interval);
- number of check bank outlets.

The impact of these parameters on system performance was studied by setting up several hypothetical design situations somewhat typical of the dimensions and parameters encountered in typical commercial layouts in southeast Australia. The range of parameter values used in the evaluation was determined through consultation with design practitioners involved in commercial designs and observation of common design practices used for these layouts. Table 1 describes the range of values used for each parameter.

Table 1
Modelling strategy used in the analysis

Design parameter	Range
Aspect ratio	0.3–1.0 (Square basin)
Longitudinal slope (%)	0.03–0.08
Inflow rate ($m^3\ s^{-1}\ m^{-1}$)	0.0013–0.0019
Local microtopography	High to low irregularities
Contour interval (m)	0.05–0.15
Outlet number	1 and 2

3.2. Evaluation criteria

In addition to time of advance, two efficiency measures and one uniformity measure are used in the assessment of hydraulic performance, namely:

- application efficiency;
- water requirement efficiency, and;
- distribution uniformity.

Application efficiency is defined as follows (Burt et al., 2000):

$$\frac{\text{average depth of irrigation water contributing to target depth}}{\text{average depth of irrigation water applied}} \times 100. \tag{1}$$

In this definition, the average depth of irrigation water applied is the total volume per unit area of inflow during an irrigation event. Because of the particular features of these irrigation systems where drainage usually occurs as backflow into the supply channel following the cessation of inflow, this term must be redefined to take into account the volume of drainage runoff occurring at the inlet end, and through the check bank between basins. The computer model calculated this term as the sum of the infiltrated depth and surface ponding following the cessation of drainage.

The water requirement efficiency is defined as (Walker and Skogerboe, 1987):

$$\frac{\text{average depth of root zone storage}}{\text{average depth of potential storage}} \times 100. \tag{2}$$

This term is intended to measure the degree to which the field has been underirrigated. The value of this parameter is always 100% when the entire field has been fully irrigated.

Uniformity of irrigation is measured by distribution uniformity (DU) which is defined as follows (Burt et al., 2000):

$$\frac{\text{average low quarter depth}}{\text{average depth of irrigation water applied}} \times 100. \tag{3}$$

The average low-quarter depth is the average depth of water applied to the 25% of the field receiving the least amount of water. This assumption implies that 12.5% of the field will be underirrigated if this parameter is used as the criterion for selection of time of cut-off and inflow discharge.

In this analysis, the soil type was assumed to be the same as that observed in the field experiments conducted on commercial contour layouts (Khanna, 2001). The target depth or readily available water (RAW) was determined using the average values of volumetric soil water content at field capacity and wilting point as described in Eq. (4):

$$\mathrm{RAW} = 0.5(\theta_{\mathrm{FC}} - \theta_{\mathrm{WP}})Z_{\mathrm{r}}, \tag{4}$$

where RAW is the readily available water in the soil (m), θ_{FC} the volumetric water content at field capacity, θ_{WP} the soil volumetric water content at wilting point and Z_{r} the root zone depth (m).

The values of soil volumetric water content at field capacity and wilting point were taken as 0.43 and 0.28, respectively, and the root zone depth was assumed to be 30 cm. These values typify the shallow rooted pasture and cereals planted in these basins. Target depth was estimated using Eq. (4) as 0.022 m. The computer model allows the use of either the Kostiakov–Lewis infiltration equation or the quasi-analytical Parlange infiltration equation. In this analysis, however, only the Kostiakov–Lewis model (Eq. (5)) was used for modelling purpose:

$$Z = kt_{op}^{a} + bt_{op}, \tag{5}$$

where Z is the cumulative infiltration per unit area (m), t_{op} the intake opportunity time, or the time since the wetting front arrived at the point in consideration, and k, a and b the empirical constants and can be determined from a simple regression analysis over the experimental $Z(t)$ data.

The following basic design parameters were used in the simulation:

- Discretisation grid size: $10\,\text{m} \times 10\,\text{m}$.
- Inflow rate per unit width: $0.00135\,\text{m}^3\,\text{s}^{-1}\,\text{m}^{-1}$.
- Infiltration parameters of Kostiakov–Lewis equation: $k = 0.055\,\text{m}\,\text{s}^{-0.026}$; $a = 0.026$; $b = 0.0\,\text{m}\,\text{s}^{-1}$.
- Manning roughness coefficient: 0.05.
- Duration of simulation: 7.0 h.

The inflow was cut-off when all the nodes in the computational domain received a minimal depth of application of 1 mm. This is intended to mimic a common practice adopted by farmers whereby the supply is cut-off when the waterfront covers the entire basin.

4. Effect of aspect ratio

Aspect ratio is the quotient between the width and the length of the basin. A single 200 m long basin was selected for the analysis of aspect ratio. The width of the basin varied between 60 and 200 m while maintaining the length constant to yield a range of aspect ratios between 0.3 and 1.0. The same topographic relief surveyed in the experimental basin used for validation of the computer model was used for the analysis. Table 2 shows the different field shapes and grid layout used for the study.

Table 2
Field size, shape and grid layout for different aspect ratio

Aspect ratio	Length (m)	Width (m)	Number of discretisation nodes (rows × columns)
0.3	200	60	21 × 7
0.4	200	80	21 × 9
0.5	200	100	21 × 11
0.6	200	120	21 × 13
0.7	200	140	21 × 15
0.8	200	160	21 × 17
0.9	200	180	21 × 19
1.0	200	200	21 × 21

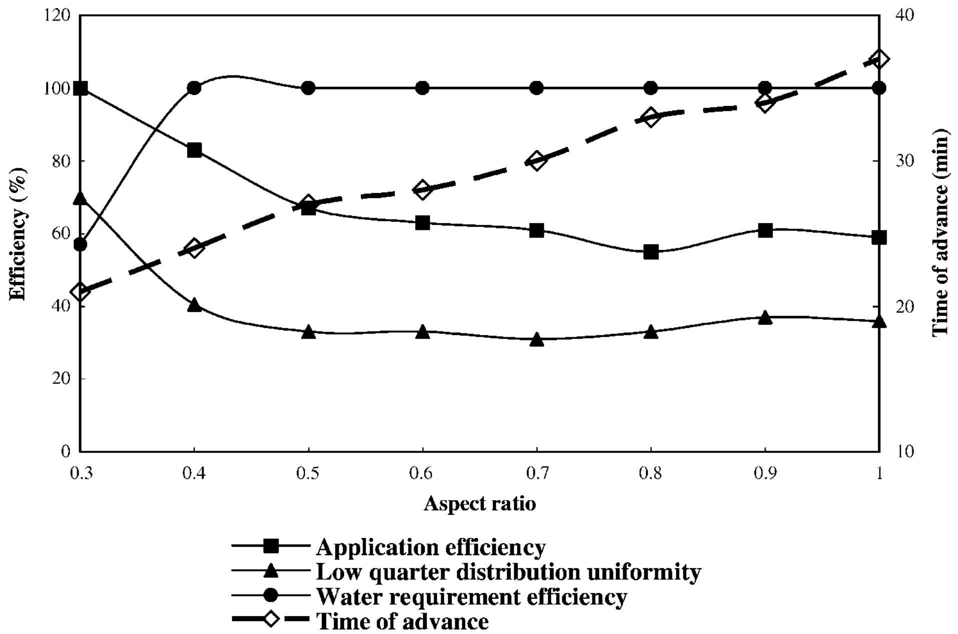

Fig. 2. Application efficiency, water requirement efficiency, low-quarter distribution uniformity and time of advance for different aspect ratios.

The water balance components were quantified to study irrigation performance for each simulation run in order to assess the hydraulic performance response to aspect ratio. Fig. 2 shows the variation of application efficiency, low-quarter distribution uniformity, water requirement efficiency and time of advance versus aspect ratio. The application efficiency declines initially with the increase in the aspect ratio indicating a reduction in irrigation performance. This is consistent with the fact that an increase in aspect ratio leads to greater deep percolation losses as the time of advance also increases. Another reason for lower application efficiency and low-quarter distribution uniformity at higher aspect ratios is the increase in inflow width and correspondingly total drainage. Irrigation uniformity shows a similar trend to application efficiency. Both indicators show a greater sensitivity in the low range of aspect ratio whereas these two parameters remain largely unchanged for greater aspect ratios.

The trend of water requirement efficiency was opposite to that shown by application efficiency. However, fields with aspect ratios greater than 0.4 were completely irrigated as a result of increased times of advance associated with greater aspect ratios that translate into larger volumes of water applied.

These results reinforce the importance of selecting an appropriate aspect ratio to achieve high efficiency and uniformity. The range of aspect ratios where efficiency is the highest, however, will vary for each design and is site specific requiring specific modelling analysis for each particular case.

The time of advance in Fig. 2 shows that it increases significantly with an increase in the width of the basin despite the inflow discharge increasing in direct proportion to the basin

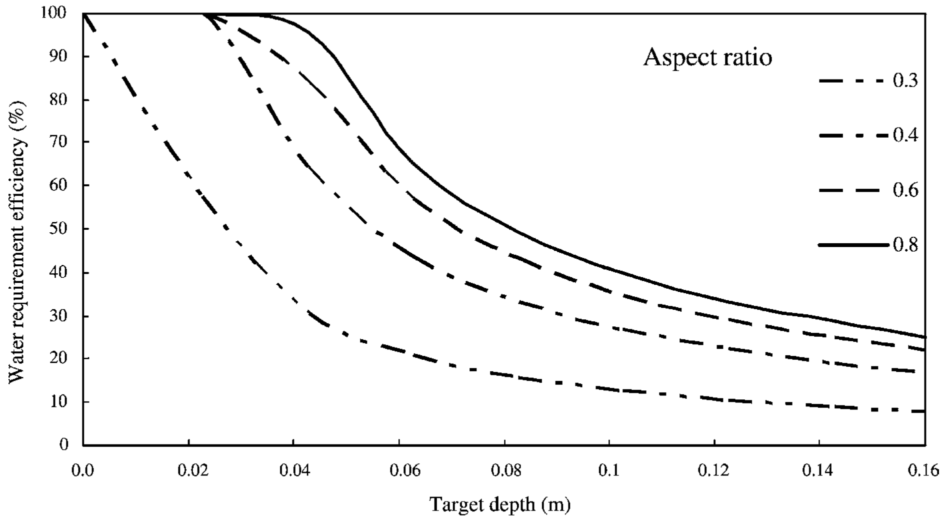

Fig. 3. Water requirement efficiency as function of target depth for different aspect ratios.

width. Since the unit inflow was maintained constant for the various basin dimensions, these results suggest that if the width of the basin increases the inflow rate per unit width should increase more than proportionally in order to maintain the same rate of advance. This increase in the time needed to flood the basin has a effect on the amount of water applied and on the decrease in irrigation efficiency given the small depth of application required for the typical crops grown in these basins.

Fig. 3 shows changes in water requirement efficiency in response to target depth for different aspect ratios. As the width of the basin decreases in relation to its length, the extent of the underirrigated area increases. The sensitivity of this parameter to aspect ratio appears to be higher for low aspect ratios than that for high aspect ratios, e.g. approaching a square basin. This is consistent with the results shown in Fig. 2 in which water requirement efficiency is more sensitive to changes in the low range of aspect ratios.

5. Effect of basin longitudinal slope

Basins are by definition irrigation units graded to zero slope in both directions. It is, however, common practice among designers to provide some slope in the longitudinal direction to facilitate advance. A simulation experiment was carried in order to ascertain the impact of longitudinal slope on performance by simulating single hypothetical contour basins. A basin of 200 m length and 100 m width was selected for the analysis. The topography was assumed to follow a regular elevation plane with local irregularities which replicate those of the experimental basin which was also used to validate the computer model. Several simulation runs were carried out varying the longitudinal slope between 0.03 and 0.08% to include the range of typical slopes used by irrigation designers. The impact of longitudinal slope on irrigation performance results is depicted in Fig. 4. The

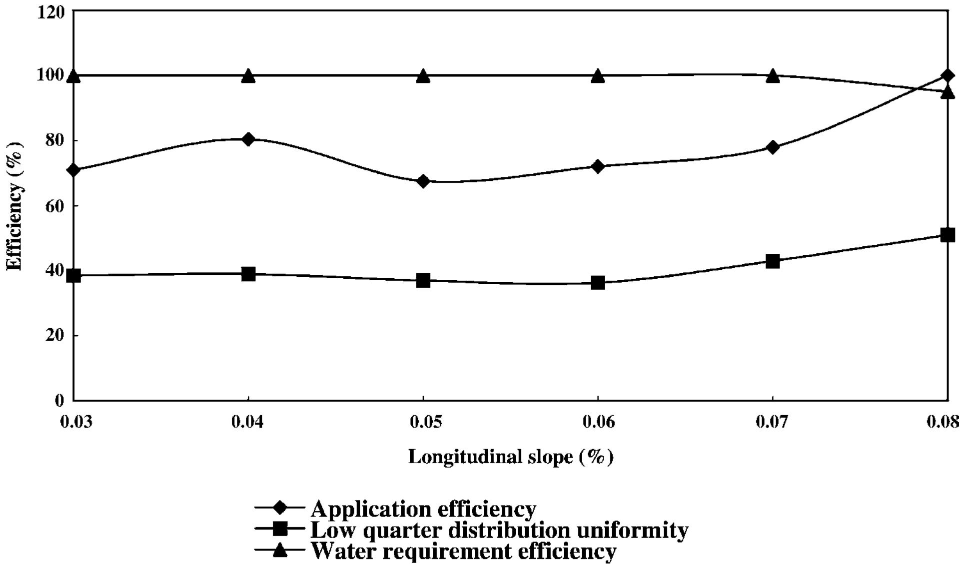

Fig. 4. Application efficiency, water requirement efficiency and low-quarter distribution uniformity for different slopes.

relationship shows that both application efficiency and low-quarter distribution uniformity while increasing slightly with an increase in slope they are relatively insensitive to this parameter. As indicated by the behaviour of the water requirement efficiency, the field was marginally underirrigated at the high end of the slope range.

Advance slope is often used by designers to favour a faster advance of the waterfront over the basin. As expected, advance time decreases with an increase in the longitudinal slope. For the particular basin simulated for this analysis, there is a 20% reduction in advance time which translates into better uniformity and reduced deep percolation. The more rapid advance occurring with steeper slopes provides a more even application over the entire field compensating for the longer infiltration opportunity time experienced by those points closer to the inflow inlet. On the other hand, it is possible that if the slope becomes too steep, part of the field may remain underirrigated. These results indicate that whilst some longitudinal slope might aid in achieving better uniformity and efficiency, the selection of best slope for the basin requires careful analysis for each case.

Fig. 5 is a plot of water requirement efficiency as a function of target depth for different longitudinal slopes. The figure indicates that for a particular set of basin dimensions there is a range of application depths for which the water requirement efficiency drops away very rapidly as rapid advance leads to underirrigation of part of the basin. It can also be observed that the rate of decline decreases beyond the range of target depths in which water requirement efficiency is highly sensitive. These results may, however, be influenced quite significantly by the type of soil used in the simulation experiment. The heavy cracking nature of the soil is reflected in the infiltration parameters used for the simulation which include a large initial infiltration rate (crack fill) followed by very low infiltration rate as the value of the steady-state rate term ($b = 0.0$).

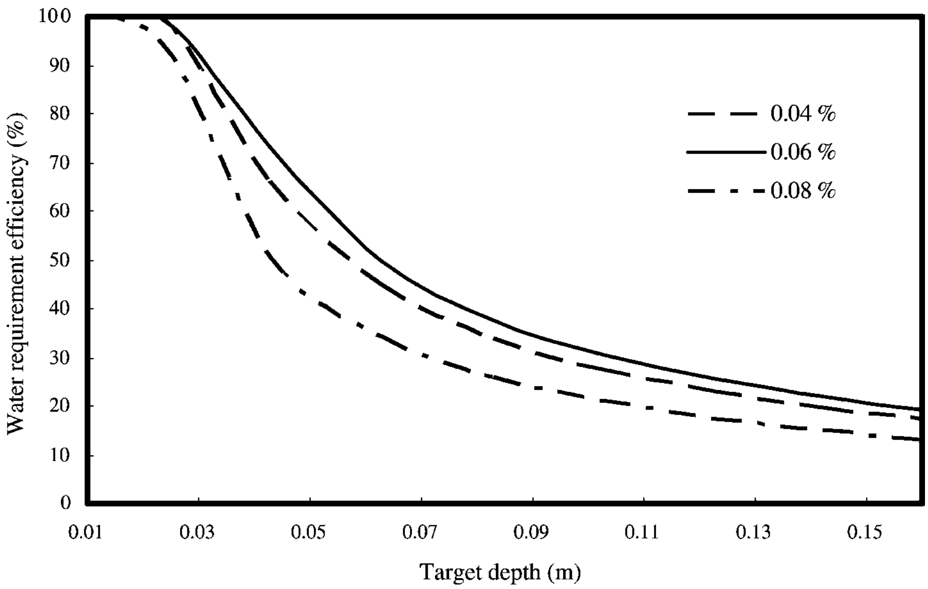

Fig. 5. Water requirement efficiency as function of target depth for different longitudinal slopes.

6. Effect of inflow rate

Supply channel discharge is an important parameter in the design and management of contour basin layouts as it determines the boundary inflow depth; and ultimately it is the key controllable design and management parameter that determines how fast a basin can be irrigated to the target depth. To study the effect of inflow rates on advance time and irrigation performance, a design basin 200 m long and 100 m wide was irrigated with line inflow from the supply channel with an average discharge varying from 0.0013 to 0.0019 $m^3\ s^{-1}\ m^{-1}$.

The relation between unit inflow discharge and uniformity, efficiency and time of advance is shown in Fig. 6. Application efficiency increases marginally with an increase in inflow rate but remains largely unchanged at higher inflow rates. This indicates that an increase in unit inflow rate can reduce deep percolation losses and improve application efficiency. It should be noted, however, that at higher inflow rates, application efficiency declines marginally indicating that gains made by faster advance are more than offset by greater percolation losses resulting from excess application. Low-quarter distribution uniformity shows in general a similar trend as application efficiency. These results indicate that higher inflows lead to high efficiencies and uniformity and but should be used judiciously to avoid an excessive application depth.

Advance time has shown to be highly sensitive to inflow rate for one-dimensional flow layouts such as furrows and borders (Clemmens et al., 1981; Wattenburger and Clyma, 1989). Similar results were obtained in this analysis as shown in Fig. 6. Advance time in contour layouts is a very important factor for crops that do not require or tolerate ponding or when the target depth of irrigation is relatively small. The objective of irrigation in this

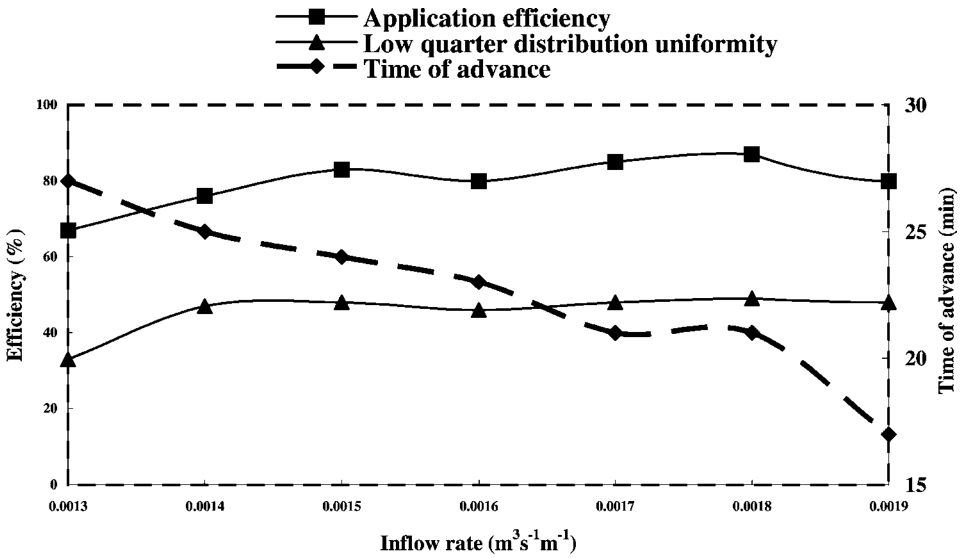

Fig. 6. Effect of inflow rates on application efficiency, water requirement efficiency, distribution uniformity and time of advance.

situation is to irrigate and drain the basin as quickly as possible given that coverage of the basin with the minimum depth of application is required.

Unit inflow rate has a similar effect on water requirement efficiency to that of longitudinal slope albeit less pronounced. Fig. 7 depicts the behaviour of water requirement efficiency for different target depths as function of inflow rates.

The relation indicates that as the inflow rate increases for a given design the amount of underirrigated area increases leading to lower water requirement efficiency. The relation also shows that for a given target depth, lower inflow rates achieve a more complete irrigation, which is opposite to the trend shown by uniformity and application efficiency. Lower inflow rates translate into longer advance times and thus greater application depth. A delicate balance always exists between water requirement efficiency and application efficiency that must be carefully analysed for each specific design. The relation is particularly sensitive in the region where the field becomes underirrigated for a particular target depth. This is followed by a rate of decrease in the degree of underirrigation. This can be explained by the cracking nature of these soils which is reflected in the high value of the crack fill term (k) and low steady-state rate ($b = 0.0$) in Eq. (5).

6.1. Effect of surface local microtopography

Local undulations on the basin's surface are an important factor affecting advance and recession (Walker and Skogerboe, 1987). These local undulations are commonly referred to as microtopography. They are significant in basin irrigation because they cause local stagnation of water and irregular advance of the waterfront. These undulations still exist in laser-levelled basins with zero or very gentle slopes. The effect of local microtopography

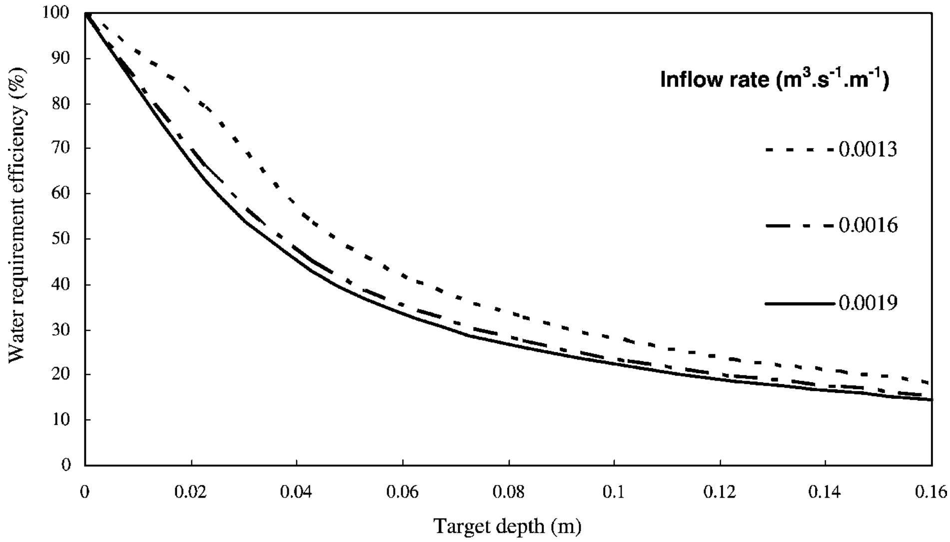

Fig. 7. Variation of water requirement efficiency with target depth for different inflow rates.

on irrigation performance was also observed by the authors during the field monitoring of irrigation events. This microtopographic irregularities cause local stagnation of water and delay in water movement.

The effect of local undulations is analysed for a hypothetical contour basin of rectangular shape with, 300 m long and 100 m wide. The basin was discretised to a $10\,m \times 10\,m$ size grid for modelling purpose. The basic slope and soil topographic elevations of the experimental basins (measured on a grid of $12.5\,m \times 12.8\,m$) were used for this simulation. The existing basin slopes along and across its length were determined using the "plane method" (Walker and Skogerboe, 1987). The deviations between the ground elevation and plane elevations were then determined and used as baseline values for the sensitivity analysis. These deviations were then contracted and expanded by between 5 and 35%. The effect of the positive increase of deviation makes the basin rougher by expanding the undulations (greater irregularities) and the negative increase results in a smoother basin by contracting the undulations (smaller irregularities). In each simulation the toe-furrow depth was kept as 0.20 m which was also the average depth of the toe-furrow in the experimental basin. The duration of the simulation was 10 h.

The relation between efficiency and the magnitude of surface irregularities shown in Fig. 8 indicates that the application efficiency and distribution uniformity both decline with an increase in roughness of the basin although this decline is less pronounced for distribution uniformity. Conversely, a positive trend for uniformity and application efficiency is observed when the basin was made smoother by reducing the local undulations. This once again emphasises the fact that the presence of pronounced local irregularities can affect efficiency and uniformity despite the field having been laser levelled as in this case. Periodic maintenance of the basin surface to eliminate or reduce the height of irregularities is required to reduce the height of the surface irregularities.

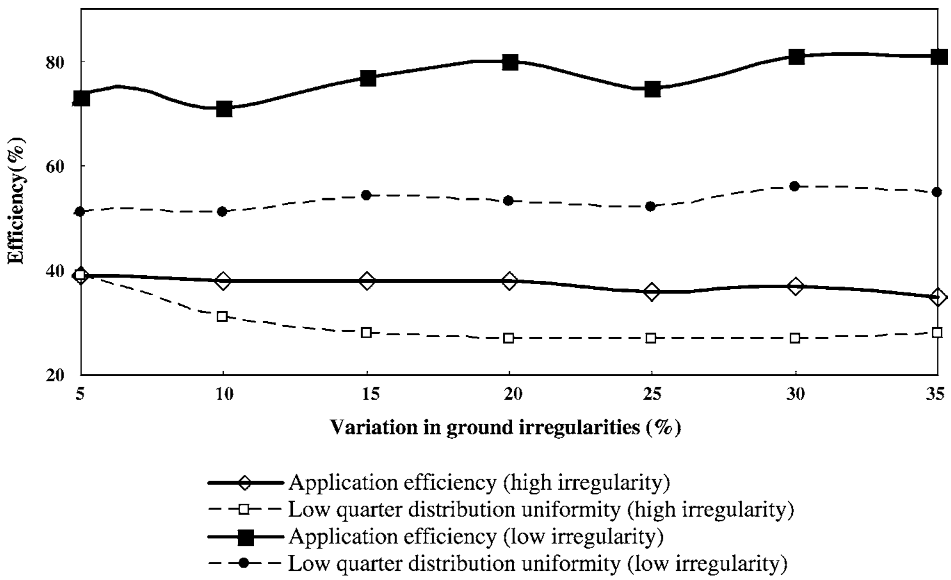

Fig. 8. Application efficiency and low-quarter distribution uniformity as a function of surface irregularities.

As expected, advance time is responsive to the magnitude of surface irregularities as shown in Fig. 9. For a basin with reduced local variations in elevation, the trend shows a reduction in the time of advance of the waterfront. Consistent with the effect of irregularities on efficiency and uniformity, there is an increase in time of advance when the irregularities are magnified. Irregularities are thus an important factor in the

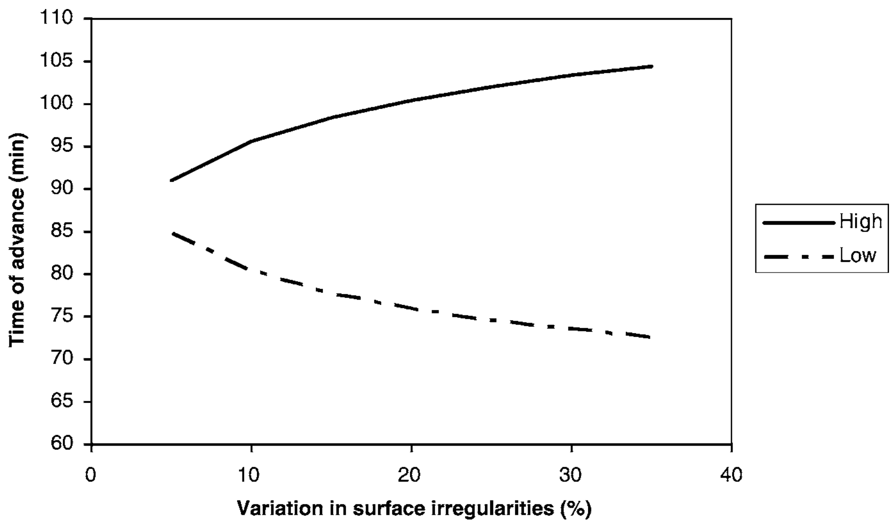

Fig. 9. Variation of time of advance with changes in surface irregularities.

management of lasered contour basin layouts, especially under the typical conditions of soils and crops grown in these basins which require small depths of application.

7. Effect of vertical interval between basins

The vertical difference in elevation between contour basins is primarily dictated by the natural land topography. Through land forming practices, however, designers can alter the elevation intervals between adjacent basins to better suit other features of the design including the elevation of the water source, supply channel and reuse pond. Swinton (1994) claims that contour layouts work best when a proper vertical interval exists between basins. The vertical interval between adjacent basins is perceived by practitioners to be an important parameter in the design of contour layouts because it affects ponding of water and drainage of excess water from the upstream basin.

For the purpose of analysing the importance of this factor, a two-basin layout was selected to determine the effect of contour interval on advance time and irrigation performance. Both basins selected were of regular shape and each with a length and width of 200 and 100 m, respectively.

The topography of the top basin was assumed to have uniform slope along the advance length (0.005%) and cross-slope (0.03%). The same topography was replicated for the second basin for differences in vertical displacement between basins ranging between 0.05 and 0.15 m.

Additional design assumptions used for both basins in this analysis are as follows:

- Inflow rate per unit width, or line inflow (first basin): 0.00135 $m^3 s^{-1} m^{-1}$.
- Line and side drainage runoff (second basin).
- Duration of inflow: until completion of waterfront advance over the entire top basin.
- Duration of simulation: 14 h.

After an initial drop in the time of advance, the rate of change for vertical displacements greater than 0.07 m becomes negligible as shown in Fig. 10. This indicates that the increase in inflow to the second basin through the check bank (drainage flow) is not sufficient to affect the time of advance in any significant way. This can be attributed to the more rapid advance of the waterfront in the toe-furrow that reduces the hydraulic gradient when the waterfront arrives at the outlet point, thus reducing the runoff discharge through the check bank from the first basin.

8. Effect of number of check bank outlets

Drainage of the basin is very important for good water and crop management. It is a common practice that in a multiple-basin operation runoff from the upstream basin drains into the downstream basin. Typically, designers use either one or two outlets in their basin designs. The amount of drainage between basins depends on the number of outlets installed in the check bank.

The effect of number of outlets between two basins on irrigation performance is analysed in this section. Two regular shape basins 400 m long and 100 m wide were selected for this

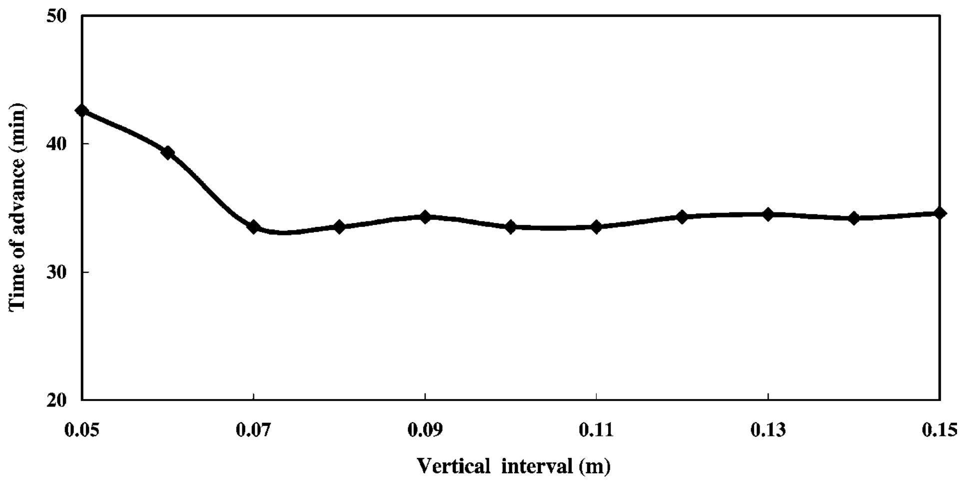

Fig. 10. Change in time of advance due to vertical interval between basins.

simulation. Both basins were discretised with a grid spacing of 10 m × 10 m resulting 41 nodes in x-direction and 21 nodes in y-direction. The vertical displacement between the top and second basins was kept as 0.08 m.

The first simulation was run with only one outlet located at a distance of 390 m from the supply channel. The number of outlets was increased to two in the second simulation, with the second outlet located at a distance of 60 m from the supply channel. The additional design assumptions used for both basins in this analysis are as follows:

- Line inflow rate per unit width (first basin): 0.00135 $m^3 s^{-1} m^{-1}$.
- Line and side drainage runoff (second basin).
- Duration of inflow: until completion of waterfront advance over the entire top basin.
- Duration of simulation: 24 h.

Table 3 shows the time of advance, application efficiency, water requirement efficiency and low-quarter distribution uniformity for one and two outlets systems for the first and second basin. These results indicate that advance time in the second basin is affected the number of outlets. Advance time in the second basin with two operating outlets was reduced by 13%. This also indicates that the first basin was better drained with two

Table 3
Irrigation performance parameters for one and two outlets between two basins

Number of outlets	Time of advance (min)		Application efficiency (%)		Water requirement efficiency (%)		Low-quarter distribution uniformity (%)	
	First	Second	First	Second	First	Second	First	Second
1	68	141	100	98	92	100	81	77
2	68	123	100	100	92	100	81	88

operating outlets. A marginal improvement is noted in the application efficiency of the second basin with two outlets while water requirement efficiency was not affected by the increase in the number of outlets. The relative lack of sensitivity of application efficiency in this particular case is closely linked to the selection of the target depth which is similar to the crack fill volume for these soils. Once the soil cracks are filled, these soils exhibit very low intake rates. This explains the minimal change observed in deep percolation losses and thus in application efficiency.

The effect on distribution uniformity was significant as it increased by 14% for the second basin with two operating outlets. This is due to the faster advance and coverage of the basin with two operating outlets.

9. Conclusions

In this study, various contour layouts and operation scenarios were modelled using the computer model COBASIM to understand the importance and behaviour of key design parameters and their relationship with irrigation performance. The effect of aspect ratio, longitudinal slope, inflow rates and local microtopography on irrigation performance in a single basin was analysed together with the vertical displacement between basins and number of outlets between connected basins in a multiple-basin system. The following conclusions can be drawn from the results of this study:

- An increased time of advance and decreasing efficiency and uniformity is observed when the aspect ratio approaches 1.0 (square basin). This suggests that as the aspect ratio increases a greater than proportional increase in inflow is necessary to compensate for the longer time required to irrigate the basin.
- A mild slope in the advance direction can assist the advance of the waterfront and reduce the time of application. This is particularly important when a shallow depth of application is required. The optimal slope, however, depends on the soil and geometric configuration of the basin.
- There are no significant benefits from increasing the vertical displacement between basins in a multiple-basin layout.
- The number of check bank drainage outlets has a significant effect on the time of advance and irrigation uniformity in the downstream basin while the effect on application efficiency is less pronounced.

These results are intended to provide assistance to designers and surveyors in conceptualising the critical design factors when approaching a new design situation. It is expected, however, that computer simulation will be used in any specific design situation to explore various specific design scenarios in order to identify the best efficiency outcome.

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