Improving the Efficiency and Flexibility of Contour Irrigation Design

Final Report

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CONTENTS

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Abstract

A physically based two-dimensional simulation model (CoBaSim) that incorporates all the main features of contour basin irrigation in South East Australia was developed in this study. The model is based on the zero inertia approximation of the two-dimensional Saint Venant Equations of motion. Infiltration is modelled using the empirical Kostiakov-Lewis equation and the quasi-analytical Parlange equation. Field studies were conducted over a period of two years (1998-2000) on commercial layouts to evaluate their irrigation performance and provide data for verification of the computer model. Comparison of model results and observed data showed that the model is capable of simulating the key hydraulic processes occurring in contour basin irrigation including wetted area during advance, waterfront advance, advance water balance and basin water balance. The model was also used to develop a set of general design and management guidelines which include aspect ratio, longitudinal slope, vertical elevation difference between basins, local microtopography and number of drainage outlets. A Windows based user-friendly interface has been developed for the model to make it accessible for use by irrigation designers and practitioners in general.

Project Objectives:

This project was designed to provide objective design criteria to establish BMPs for ponded contour irrigation layouts. It was envisaged that by constructing a validating a computer simulation model it would be possible to provide the capability to develop general design and management guidelines and carry out the design of individual layouts.

The objectives as agreed in the original Project Schedule and the subsequent amendement of 1 December 2000 were:

- To develop a hydraulic model for simulation of water flow and infiltration within contour irrigation.
- To use the model to assess the efficiency of current irrigation practice.
- To use the model to develop and demonstrate design and management guidelines for contour irrigation layouts.
- To develop the model into a user-friendly design and management software for use by practicing surveyors/designers.

Achievement of Objectives

Objective 1:

To develop a hydraulic model for simulation of water flow and infiltration within contour irrigation

Model development

This section deals with the development of a physically based two-dimensional simulation model which incorporates the main features of contour basin irrigation layouts as practiced in South east Australia. The main features of these layouts are their irregular shapes, the presence of toe-furrows, multiple inflows and outflow points and multiple bay operation. The model is also capable of incorporating microtopography to consider its effect on the advance and recession phases of an irrigation event.

The mathematical model is based on the two-dimensional simulation of overland flow coupled with an infiltration model that describes the subsurface flow. The model can accept both the Kostiakov-Lewis and Parlange infiltration equations. Overland flow is described by a zero-inertia approximation to the Saint Venant equations of motion. These equations neglect the local and convective acceleration terms in the momentum equation.

In its present state, the model has the following capabilities:

- It can simulate regular and irregular shape bays
- It can simulate multiple bay systems
- It can simulate different types of inflows such as line inflow and point inflow or combination of both
- It incorporates microtopography by taking elevation of the grid points in the basin.
- It models multiple outflow points in the basin.

- It includes the effects of toe-furrows.
- It incorporates infiltration using Kostiakov-Lewis empirical equation or quasi-analytical Parlange equation.
- It can set the inflow boundary as depth of flow or supply ditch flow rate.
- Outputs from the model are flow depth, arrival time of waterfront, outflow from the basin and infiltrated depths.

Appendix 1 gives a detailed decription of the model formulation and its numerical scheme.

Model Validation

The computer model was validated against data collected from field experiments carried out on commercial layouts. Various scenarios of contour layouts were used for the validation of model.

The validation of the model commenced during the first year of the project (1998/99) against field results obtained during that season. This stage of the validation was carried out in parallel with the development of the model during the first phase of the project. The validation of the model was completed during the second year of the project against additional field data collected during the 1999/00 season.

The validation of the model was carried out against the main hydraulic and geometric features of typical a commercial contour basin system for double purpose cropping. These include:

- Basin topographic relief
- Capability to describe advance and recession
- Capability to simulate multi-basin systems
- Capability to include tow-furrow and multiple inflow and outflow points.

The detailed validation results are shown in Appendix 1 together with irrigation performance data collected during both irrigation seasons. The model was validated against a combination of geometric configurations, infiltration models, and water supply arrangements including:

- Single-regular basin model with Kostiakov and Parlange infiltration equations
- Multiple-irregular basin model with Kostiakov-Lewis model.

The model outputs used to measure the performance of the model under the various validation scenarios include:

- Cumulative wetted area
- Water front pattern
- Advance water balance
- Overall basin water balance

The model performed well against all the field observed data. The model performance was determined by its ability to duplicate the field processes. In all cases the deviations observed between measured and simulated outputs are well within the expected range. Variations in the quality of simulation normally occur as a result of uncontrolled modelling variables such as variability of infiltration characteristics, micro-relief and ability to control fluctuations in inflow rates. The validation of the model against field measurements from a typical commercial layout assumes that a similar level of variability in these design variables can be expected from other commercial layouts. A detailed description of the model validation results is provided in Appendix 1.

Summary and conclusions from model development and validation

- The zero-inertia approximation based mathematical model coupled with the Kostiakov-Lewis or Parlange infiltration equations is capable of simulating the main hydraulic processes involved in contour basin layouts. The model proved to be numerically stable for a number of design scenarios and range of model parameters.

- The validation of the mathematical model was carried out against data collected from a typical commercial layout. The model outputs closely matched the behaviour of a typical commercial layout. Model validation included data from two irrigation seasons as well as first and later irrigations during the season and single basin and multiple basin layouts.

- Wetted area and waterfront pattern simulated by the model compared very well with field data collected from single basin and multiple basin layouts with deviations not exceeding 9% in all cases. These included simulations carried out using both the Kostiakov-Lewis' and Parlange's infiltration models.

- The simulation of volume balance during advance matched the field data satisfactorily. A larger deviation was observed in the second basin of an irregular shape basin layout where the initial stages of the irrigation event shows a larger deviation although the simulation of the total aggregate area was within 10%.

- The comparison of water balance components between model simulation and field measurement for a multiple basin layout shows deviations between 7% and 30%. The simulated mass balance for the top basin in a set of two basin was within 7% of the measured infiltrated volume while the simulation of the second basin was within 30% of the infiltrated volume. The accuracy of the mass balance simulation is heavily dependent on the infiltration parameters used in the simulation.

Objective 2

To use the model to assess the efficiency of current irrigation practice

Field experiments

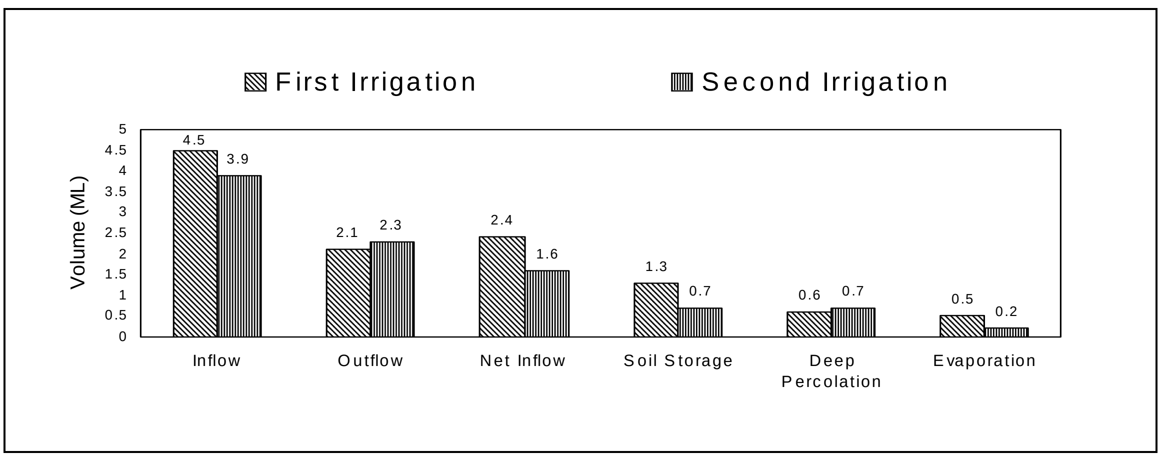
Irrigation trial (1998-99)

This section reports on the assessment of current irrigation practices in typical of double purpose contour basins. Field experiments were carried out on a commercial farm for a period two years with the double purpose of evaluating the performance of the existing layout and collect basic hydraulic and soil data for the validation of the mathematical model.

The collection of field irrigation performance data comprised two phases: (a) An initial “shake down” experiment designed to trial the methodology to monitor advance and recession of water over the field conducted at the NSW Agriculture Experimental Station; and (b) monitoring of a full scale commercial contour basin system during the irrigation season 1998-99 and 1999-00. In addition, soil basic properties of the contour bay used in monitoring were also determined. These experiments were all conducted on Bill Rumble’s property at Wyanda near Deniliquin, NSW. The details of the experimental technique are given in Appendix 2.

Two irrigation events were monitored during each season. In each case a combination of inflow and outflow management practices were used including line inflow from the supply channel and a combination line inflow and drainage runoff from the upper basins. The trials included both monitoring of a single basin (first year) and multiple basins (second year).

Figure 1 A water balance was calculated for each irrigation event showing that in general irrigation efficiency in this layout is poor. The volume of water used in the second irrigation was reduced by 13% due to the soil being comparatively less cracked than in the first irrigation. This allowed a faster advance and coverage of the entire basin thus reducing the volume of inflow.



- Figure 1. Water balance for irrigation events monitored during the 1998/99 season.

It can also be observed that the outflow from the bay amounted to almost 50% of the total inflow during the first irrigation and 59% during the second irrigation. This occurred as backflow into the supply channel and drainage runoff flowed into the second basin. More importantly is the fact that a large amount of water was lost to deep percolation contributing to water table accession. The toe furrows during the first set of experiments were in poor condition which precluded the excess water ponding after the inflow cut off to drain from the basin.

Multiple Irrigation trial (1999-2000)

The 1999/00 trials were conducted on the same property with the objective of collecting data to analyse the performance of multiple basin system and model verification. Table 1 presents the irrigation performance results for both trials. The ratio of deep percolation to net inflow shows similar proportions for both basins and irrigation events with the exception of the second basin results for the first irrigation. These results are better than the first irrigation primarily as a result of improved drainage conditions in the toe furrows.

- Table 1. Summary of water balance relations for the 1999/00 experimental results

	$\frac{\text{Deep percolation}}{\text{Net inflow}}$		$\frac{\text{Net inflow}}{\text{Total inflow}}$	
	Top basin	***Second basin***	***Top basin***	***Second basin***
First Irrigation	22.0	37.0	51.5	41.3
Second Irrigation	22.0	20.2	42.0	38.0

The proportion of net inflow to total inflow also improved in the second irrigation of the season as a result of improved drainage conditions. This is an important parameter in the management of contour basins since a greater proportion of net inflow leads to increased deep percolation.

Conclusions from the assessment of current irrigation practices

- Performance analysis of existing layouts shows that the net inflow (total inflow – drainage) is very sensitive to the time it takes for the excess ponding water to drain off the basin after inflow is cutoff. The condition of toe-furrows and number of drainage points between bays is the main factor in delaying drainage from the basin.
- Net inflow was shown to be high in relation to the amount of water that was actually needed to refill the soil storage leading to large deep percolation losses. Again, this is primarily determined by the ability of the bay to drain the excess water quickly.

Objective 3

To use the model to develop and demonstrate design and management guidelines for contour irrigation layouts

This section describes the hydraulic behaviour of contour basins in response to several design variables. The computer model CoBaSiMM (Contour Basin Simulation Model) was used analyse the performance of single and multiple basins in relation the following design parameters:

- Aspect ratio
- Longitudinal slope
- Microtopography
- Vertical interval between basins.
- Number of drainage outlets

The analysis is based on the study of a hypothetical layout similar to that used for the field experiments which is somewhat typical of the dimensions and parameters encountered in commercial layouts.

Irrigation performance was measured by the time of advance needed to cover the entire basin area and a combination of application efficiency, water requirement efficiency and distribution uniformity. A summary of results is provided below and a detailed definition and analysis of these parameters and the data used in the analysis are given in Appendix 3.

Aspect ratio

Aspect ratio is the quotient between the width and the length of the basin. A single basin 200 long was selected for the analysis of aspect ratio. The width of the basin was varied between 60 m and 200 m to provide a range of aspect ratios between 0.3 and 1.0. The same topographic relief of the experimental basin was used for the analysis. Time of advance increased significantly with an increase in the basin width despite the inflow discharge increasing in proportion to the basin width.

Application uniformity decreases as the aspect ratio approaches 1.0 (square basin) This can be ascribed to an increase in deep percolation losses as the time needed to complete the basin coverage increases. The same trend is observed for irrigation uniformity.

Effect of advance slope

It is a common practice among designers to provide some grade in both directions to irrigation basins to aid the advance of water over the field. The effect of grade in the advance direction was evaluated by varying the slope between 0.03% and 0.08%. Both application efficiency and uniformity show an improving trend with an increase in slope within the tested range. This is due to faster advance of the waterfront over the basin which reduces the difference in infiltration time between the inlet and bottom of the basin. The faster advance that occurs with steeper slopes tends to even out the application time between the inlet and bottom parts of the basin. The optimal slope for each design however must be determined on a case by case basis by the application of the computer model to take into account the complex interactions between geometric shape of the basin and soil and hydraulic parameters.

Effect of local micro-topography

Local undulations on the basin's surface are an important factor affecting advance and recession. 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.

The effect of local topography was analysed by simulating the irrigation of a rectangular shape basin 200-m long by 100-m long. The relief of the experimental basin was replicated and used as baseline micro-topography. The deviations between the actual elevations and a theoretical "best-fit" average plane were then increased and decreased by between 5% and 35% to make the basin rougher (increase) and smoother (decrease). Analysis of the simulation results shows that the efficiency and uniformity of irrigation is highly affected by surface irregularities. Irrigation efficiency fell by nearly 40% when the ground surface irregularities were increased by 35% over the natural condition of the basin. These results suggest that the maintenance of the basin surface to reduce irregularities is important to improve basin performance.

Effect of vertical interval between basins

In most cases the elevation difference between adjacent basins is dictated by the natural land topography. In some cases, designers may wish to change the basin elevation to better suit other features of the design including the elevation of the water source, supply channel and reuse pond. A two-basin layout of the same dimensions as that used in the field experiment was simulated to analyse the effect of vertical elevation difference between basins. The same topographic relief was replicated for the two basins changing the elevation differences between 0.05 m and 0.15m.

Overall the impact of elevation difference is relatively small with application efficiency and distribution uniformity decreasing with an increase in the vertical displacement between basins.

Effect of number of drainage outlets

It is common practice that in a multiple-basin operation, runoff from the upstream basin drains into the downstream basin outlets provided on the side check bank between basins. The effect of number outlets was analysed by simulating the operation of two hypothetical basins of regular shape 400 m in length and 100 m in width. The first simulation considered a single outlet located at 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 analysis of simulation results show that the number of outlets did affect the advance time for the second basin which was reduced by 13% when a second drainage outlet was used. This also indicates that the top basin was better drained with two operating outlets. Application efficiency improved marginally for the second basin with two outlets. Distribution uniformity showed a significant increase of about 11% with two drainage outlets. The higher uniformity of irrigation can be ascribed to faster advance and more even application in the second basin with two outlets.

Design and management guidelines

- 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 water front 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.
- Local micro-topography has an important effect on the efficiency and uniformity of contour basins. Application efficiency was reduced by 40% when the ground surface undulations were increased by 35% over the natural condition of the basin.
- There are no benefits from increasing the vertical displacement between basins in a multiple basin layout.

Objective 4

To develop the model into a user-friendly design and management software for use by practicing surveyors/designers

The computer model CoBaSim (Contour Basins Simulation Model) initially developed to simulate the surface and subsurface hydraulic processes involved in contour basin irrigation was embedded in a Windows based interface to provide a user-friendly environment for design practitioners. The interface enables the user to input the necessary data to input the necessary data to run the simulation engine and obtain screen or printed reports of the model outputs.

The model can deal with most of the typical design scenarios encountered in practice. The more important features of the software are the ability to:

- Deal with irregular quadrilateral basins
- Deal with multiple basin systems (3 basins)
- Use alternative types of inflow: continuous life inflow and point inflow or a combination of both.
- Incorporate micro-topography of the basin surface
- A seamless Windows based interface with the simulation engine

The software can simulate a system of up to 3 basins. This range would encompass most of the typical designs situations encountered in practice. Whilst often there are systems with more than 3 basins, our analysis shows that the influence of upstream basins on system performance becomes almost negligible compared with the significant computational overhead imposed by a larger number of basins. For systems with a greater number of basins can be assumed that additional basins under similar management will have a similar performance level.

The model has been tested with a number of design data sets obtained from irrigation designers representing a range design scenarios typically encountered in practice. However, as with any numerically based application, the application of CoBaSim to specific situations my involve parameter combinations that may violate assumptions or are beyond the capacity of the various algorithms resulting in unanticipated numerical stabilities.

Appendix 4 contains the detailed User's Guide for the CoBaSim software. The User's Guide discusses the basic structure of the model and the instruction for use. Some sections of this report have been repeated in the User's Guide for this is intended to be a stand-alone document.

Dissemination of results

Project dissemination

A total of three meetings of the steering committee and two workshops were held during the duration of the project. At these meetings, progress of project activities and research results were presented and discussed. The researche team also obtained useful feedback on the development of the computer model CoBaSiM from these meetings.

In addition, the research team maintained numerous discussions and contacts with individuals associated with the project in relation to the development and validation of the computer model. The model was tested with several data sets obtained from designers. This interaction proved to be invaluable to iron out the usual problem arising from designing a software package intended for regular users.

Future dissemination

A two-tier strategy for future dissemination of results from this project is needed. This should include the dissemination of the experimental and modelling results and the dissemination and adoption of the computer model CoBaSiM by design practitioners and researchers alike.

Research results have already been presented at scientific conferences both in Australia and overseas and to the stakeholders during the course of the project. There is however a need to continue disseminating these results especially by the Land and Management Groups and directly to irrigators.

This is the first version of the computer model and it is customary with any new software there will bel suggestions for changes and improvements as more people begin to use it. This is in fact a common form of development and upgrade process in the software industry. The research team will be able to support the current version of the software and will be able to respond to questions about its use and interpretation of results. Future upgrades of the software will depend on the level of uptake and the need for changes expressed by users.

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APPENDICES

Appendix 1: Model Development and validation

Model development

The design and management of contour basin irrigation layouts for rice and non-rice crops requires the ability to simulate overland flow, infiltration and drainage behavior. Several two-dimensional mathematical models have been developed for simulation of overland flow conditions in basin irrigation (Playan et al. 1994a; Singh and Bhallamudi 1997; Strelkoff et al. 1996). Playan et al. (1994a,b) and Singh (1997) developed two-dimensional basin irrigation models based on shallow water equations using the Kostiakov-Lewis infiltration model. Strelkoff et al. (1996) developed their simulation model based on zero-inertia approximation to the Saint Venant equations of motion whereas Playan et al. (1994a) solved the governing equations of the model using a fully explicit leaf-frog finite difference numerical scheme. The model was used to simulate the overland flow in basin irrigation with different inflow conditions and for irregularly shaped field. Singh and Bhallamudi (1997) used a finite volume technique in conjunction with explicit predictor-corrector finite difference approach to solve the shallow water flow problem. This model was validated using the same field data used by Playan et al. (1994a, b). Strelkoff et al. (1996) solved the governing equation using fully implicit, non-linear finite difference scheme and results were compared with field observations. The model can also be used with highly irregular bottom configurations. The drawback of the model is its computational inefficiency due to implicit nature of the numerical scheme. These models are used for closed basins where drainage from the basin and chain watering are not considered. None of these models are able to describe contour basin irrigation systems due to its peculiar characteristics such as toe-furrow and outflow from the basin common in South East Australia.

In the present study, a physically based two-dimensional simulation model for contour basin irrigation was developed. The objective of the model is to incorporate all the features of contour basins described above. The model is based on the zero-inertia approximation to the Saint Venant equations of the motion. These equations are obtained by neglecting the local and convective acceleration terms in the momentum equation. Under typical irrigation situations these terms become small compared with those describing the effect of gravity and friction in shallow water situation. When these acceleration terms are neglected, the equations of motion may be transformed into a single non-linear advection-diffusion equation, in which friction forces are described by using Manning's equation. The governing equation in advection-diffusion form is given by

$$\frac{\partial H}{\partial t} + U\frac{\partial H}{\partial x} + V\frac{\partial H}{\partial y} = D_x\frac{\partial^2 H}{\partial x^2} + D_{xy}\frac{\partial^2 H}{\partial x \partial y} + D_y\frac{\partial^2 H}{\partial y^2} - I_s \quad (1)$$

where U and V are given by,

$$U = -\frac{5}{3n}\frac{(H - z_0)^{2/3}}{\left(\left(\frac{\partial H}{\partial x}\right)^2 + \left(\frac{\partial H}{\partial y}\right)^2\right)^{1/4}}\left(\frac{\partial H}{\partial x} - \frac{\partial z_0}{\partial x}\right) \quad (2)$$

$$V = -\frac{5}{3n}\frac{(H - z_0)^{2/3}}{\left(\left(\frac{\partial H}{\partial x}\right)^2 + \left(\frac{\partial H}{\partial y}\right)^2\right)^{1/4}}\left(\frac{\partial H}{\partial y} - \frac{\partial z_0}{\partial y}\right). \quad (3)$$

The diffusion coefficients D_x , D_{xy} and D_y are given by,

$$D_x = \frac{(H - z_0)^{5/3}}{n} \frac{\frac{1}{2}\left(\frac{\partial H}{\partial x}\right)^2 + \left(\frac{\partial H}{\partial y}\right)^2}{\left(\left(\frac{\partial H}{\partial x}\right)^2 + \left(\frac{\partial H}{\partial y}\right)^2\right)^{5/4}} \tag{4}$$

$$D_{xy} = \frac{(H - z_0)^{5/3}}{n} \frac{\frac{\partial H}{\partial x}\frac{\partial H}{\partial y}}{\left(\left(\frac{\partial H}{\partial x}\right)^2 + \left(\frac{\partial H}{\partial y}\right)^2\right)^{5/4}} \tag{5}$$

$$D_y = \frac{(H - z_0)^{5/3}}{n} \frac{\left(\left(\frac{\partial H}{\partial x}\right)^2 + \frac{1}{2}\left(\frac{\partial H}{\partial y}\right)^2\right)}{\left(\left(\frac{\partial H}{\partial x}\right)^2 + \left(\frac{\partial H}{\partial y}\right)^2\right)^{5/4}}. \tag{6}$$

Equation (1) describes two-dimensional overland flow in advection-diffusion form including infiltration. The left-hand side of the equation is the advection component with U and V as advected velocities. The right-hand side is diffusion component with D_x, D_y and D_{xy} as diffusion coefficients. This is similar to advection-diffusion equation for scalar transport. Infiltration is considered as sink term on right hand side.

The model is designed to incorporate alternative infiltration equations. Infiltration rate is described by the empirical Kostiakov-Lewis equation and by the quasi-analytical Parlange equation developed by Haverkamp et al. (1990). The governing equations of the model are non-linear differential equation, which are solved by numerical approximations.

The advection component of the governing equation is solved by using the methods of characteristics with cubic spline interpolation. The diffusion component is then estimated by using cubic spline interpolation. This approach provides an alternative to the existing methods for advection-diffusion type equations with nearly same accuracy while improving the computational efficiency and code size.

The numerical scheme described above using advection-diffusion coupled with bicubic spline methodology is limited to regular grids. Contour basin irrigation layouts are sometimes irregular in shape even after laser grading. It is essential to devise a numerical scheme that offers maximum geometrical flexibility in terms of the shape of the computational domain.

A simpler approach is adopted in this study using two-dimensional Taylor series expansion (Korn and Korn 1961) about five nodal points in computational domain to estimate the unknown functions. The advection and diffusion components of governing equation are solved by using two-dimensional Taylor series expansion. This enables considerable savings in computational effort by avoiding the computational effort necessary to fit the local expansions with the discrepancy smaller than the error that is expected for the given grid size and order of expansion (Kochavi and Segev 1991).

Initial, flow, no-flow and internal boundary conditions are specified in a same manner as in the case of regular grid numerical scheme.

The model has the following capabilities

- It can simulate regular and irregular shape bays with different numerical schemes.
- It can simulate multiple bay operation.
- It can simulate different types of inflows such as line inflow and point inflow or combination of both
- It incorporates microtopography by taking elevation of the grid points in the basin.
- It includes the effects of the toe-furrow.
- It describe infiltration using either the Kostiakov-Lewis empirical equation or the quasi-analytical Parlange equation.
- It sets the inflow boundary as depth of flow or supply ditch flow rate.
- Output of the model is flow depth, arrival time of waterfront, outflow from the basin and infiltrated depths and irrigation efficiency and uniformity.

Model Validation

The two-dimensional simulation model that was developed to simulate hydraulic processes present in contour basin irrigation incorporates all the features of these layouts in South East Australia. Monitoring of a commercial layout located near Wyanda, NSW was conducted during two seasons. The purpose of irrigation monitoring trials was to study the hydraulic behaviour of the layouts, to assess the irrigation performance and to collect data for validation of simulation model.

The first two aims of monitoring were described in Milestone report 1. The following analysis focuses on the third monitoring aim- the validation of the computer simulation model.

Four groups of design and management factors were considered in the validation:

- Type of layout: Single and multiple basin
- Basin type: Regular and irregular basin shape
- Infiltration equation: Kostiakov and Parlange infiltration models
- Inflow boundary conditions: Line inflow and point inflow.

The results from the model simulation were contrasted against a set of validation variables including:

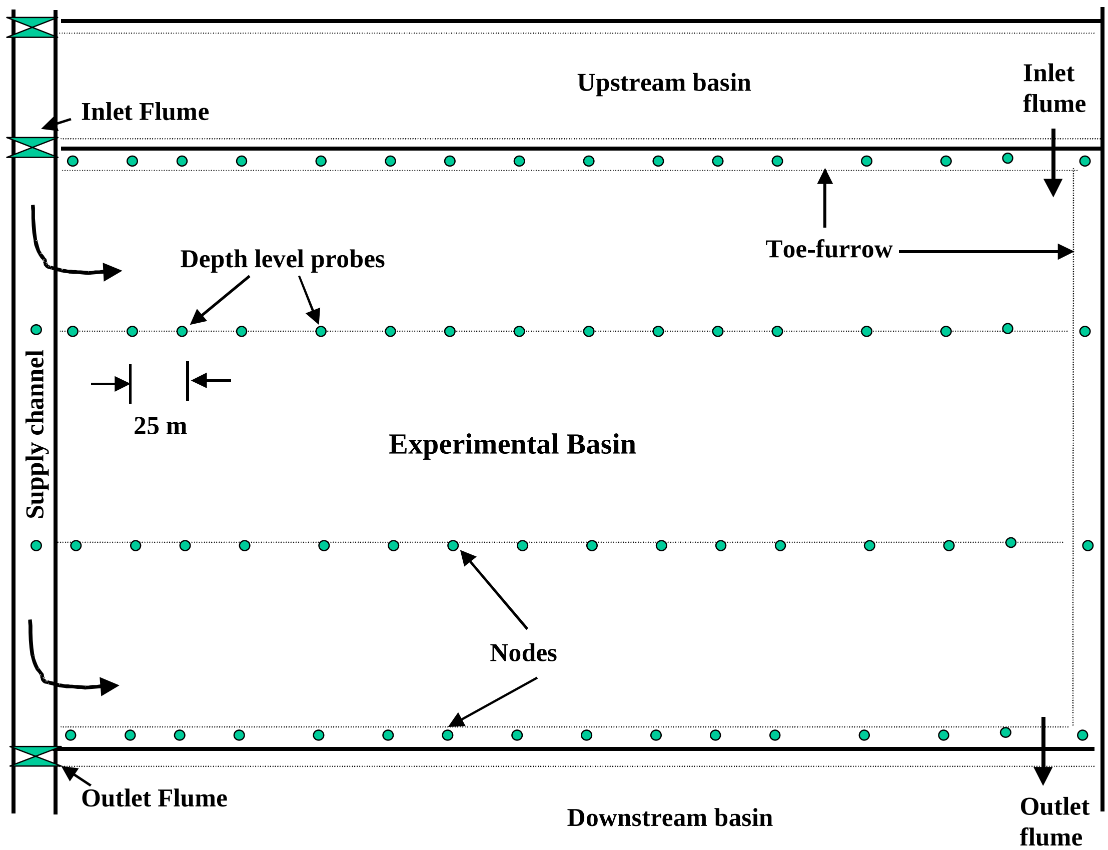
- Cumulative wetted area during advance
- Water front pattern
- Advance water balance during advance
- Overland flow depth
- Basin water balance

The following sections present a summary of the main validation results.

Validation of single regular basin model using Kostiakov-Lewis infiltration equation

Irrigation with line inflow

This option of the model was validated using the field data collected during the irrigation event monitored during the 1998/99 irrigation season. Figure A1- 1 shows the layout of regular shape experimental basin used to validate the model. In the model, infiltration was estimated using the empirical Kostiakov-Lewis equation.



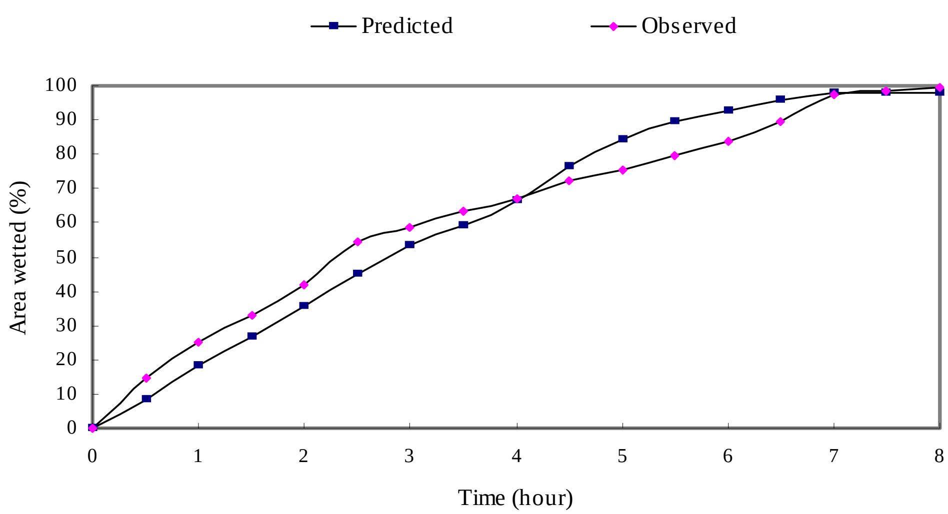
• Figure A1- 1. Layout of regular shape experimental basin.

In the first irrigation a contour basin with a toe-furrow on three sides was irrigated using line inflow from the supply channel with an average discharge of 0.15 m^3/s for 8.33 hours (Actual supply discharge varied from 0.18 to 0.12 m^3/s). Field and grid nodes were mapped using a GPS (Global Positioning System). The GPS was also used to monitor the advance of the waterfront over the field by walking along the waterfront line. Outflow was allowed back into the supply channel after the inflow was cut off.

The values of the infiltration parameters for the model were taken from the studies conducted in an area with similar soil type in the vicinity of the experiment. The infiltration parameters of Kostiakov-Lewis equation were taken as k = 0.055 m/s$^{0.026}$; a = 0.026; b =0.000000833 m/s. (Maheshwari and Jayawardane 1992; Hume 1993). The Manning roughness coefficient was taken as 0.29 as the soil was completely dry and heavily cracked. Actual ground elevation data were used in the simulation. The contour basin was discretised in a 6.25 m and 6.4 m grid size yielding a total of 806 nodes, 62 in the x direction and 13 in the y direction. Elevations of additional intermediate nodes were determined using linear interpolation of the data observed (only 217 node elevations were obtained during the survey of the field). The model was run for a total simulation time of 43 hours. Recession was very slow as outflow was allowed only as backflow into the supply channel. In common practice farmers allow water to drain back into the supply channel as well as into downstream basin from points located on the check bank.

Area wetted vs advance time

Figure A1- 2 shows the comparison between cumulative calculated by themodel and observed in the field during the advance phase. It can be observed from the chart that the numerical results obtained using the proposed model satisfactorily match the field data. Variations between the observed and predicted data can be ascribed to spatial variation in topography and soil characteristics.



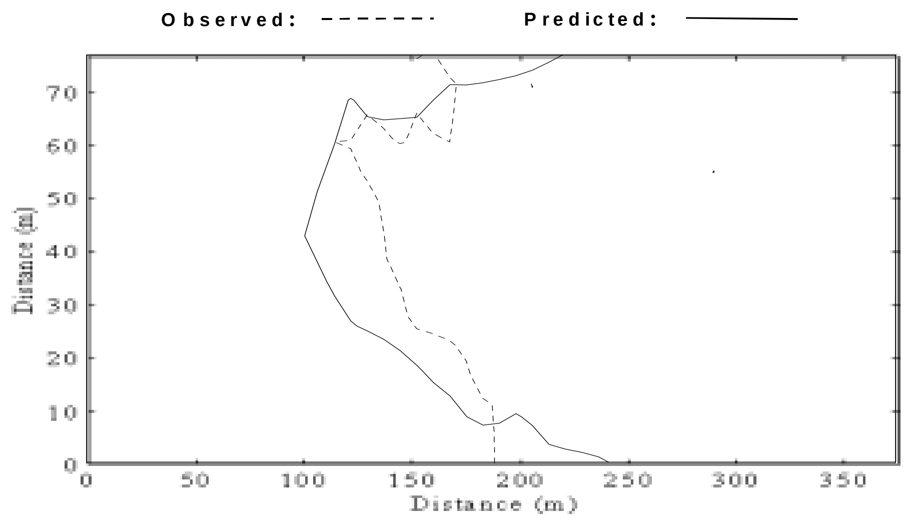
- Figure A1- 2. Area wetted during advance for regular basin model with line inflow

Waterfront advance pattern

The configuration of the water front after 2 hours of irrigation is shown in Figure A1- 3. It can be observed from the chart that the waterfront advance simulated by the model satisfactorily matches the field data. Variation in the waterfront configurations can be attributed to variation in land microtopography, local undulations due to sheep and vehicle tracks and varying soil characteristics. These results indicate that the model has the capability of simulating the behaviour of overland flow with satisfactory accuracy using a line inflow boundary condition.

Volume balance during advance

The comparison of water volume predicted by the model with that observed in the field is shown in Figure A1- 4. The predicted volume of water during advance which consists of overland volume and infiltrated volume compares very well with the observed volume. The deviation between observed and predicted volume ranges from 1% to 9% of the observed value. The reason for this deviation could be attributed to the error in computing the infiltrated volume by the model resulting from the spatial variability in infiltration.



• Figure A1- 3. Comparison of observed and predicted waterfront advance after 2 hours.

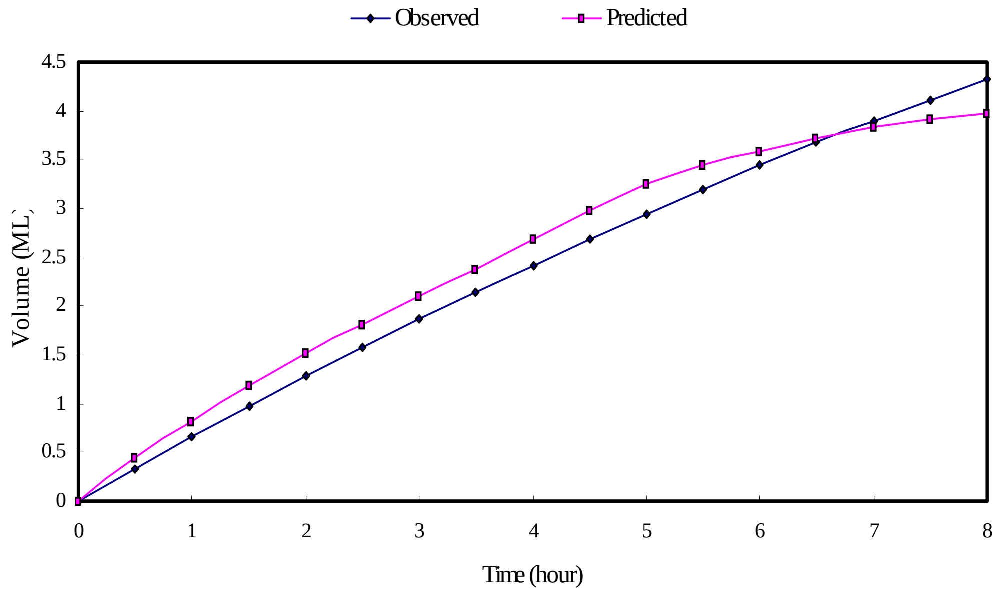
Second irrigation with line and point inflow with Kostiakov-Lewis infiltration equation

During the second irrigation of the season, the basin was irrigated from the side supply channel with an average discharge of 0.2 m^3/s for 4 hours. Water was also supplied from an inflow point (drainage runoff) from the upstream basin. The average flow rate used in the model was 0.1 m^3/s which is the same value observed during the field trial. After the inflow was cutoff, outflow was allowed back into the supply channel and from the bottom side of the basin to the downstream basin through the check bank.

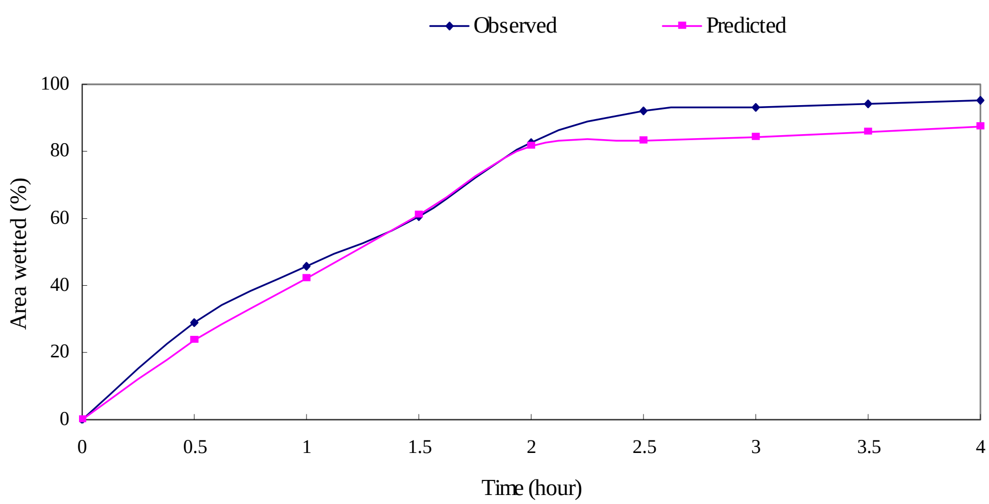
The Manning coefficient for the simulation of irrigation event was taken as 0.065 as the soil was wet and all the cracks were closed indicating less resistance to flow compared to the first irrigation. Infiltration parameters were taken as k =0.037 $m/s^{0.021}$; a =0.021; and b =0.000000833 m/s. (Maheshwari and Jayawardane 1992). The model was run for a total of simulation time of 24 hours.

Area wetted vs advance time

Figure A1- 5 shows the comparison of observed advance trajectory with model predicted advance time. This indicates that the model predicts the area wetted during the advance phase for irrigation with line combined with point inflow with good accuracy. The final predicted wetted area for the complete advance phase is about 9% less than the observed wetted area. The minor variations in predicting the wetted area are due to the same reasons mentioned in earlier sections such as soil variability, minor topographic undulations and variability of infiltration parameters.



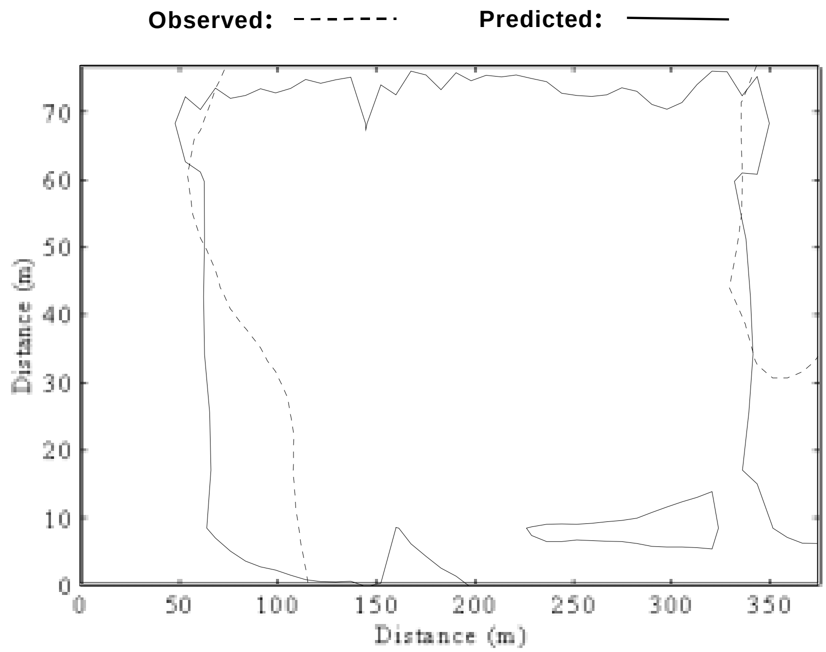
• Figure A1- 4. Comparison of predicted and observed water volume during the advance phase



• Figure A1- 5. Wetted area during advance phase for regular basin model with line and point inflow.

Waterfront advance pattern

Figure A1- 6 shows the waterfront advance pattern comparison after 30 minutes and one hour respectively during the simulation of irrigation event with both line and point inflow during the second irrigation. This simulation once again indicates the capability of the model for incorporating both line and point inflow simultaneously.

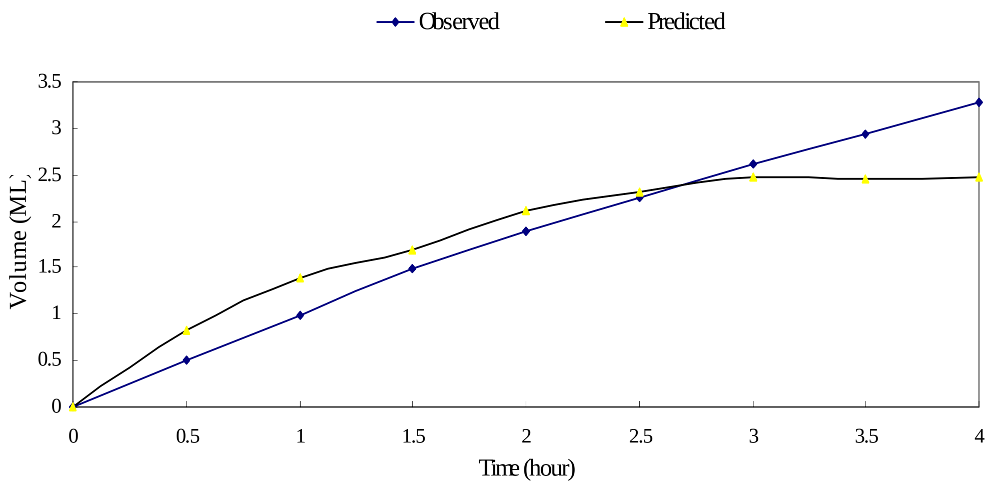


- Figure A1- 6. Water front pattern after 30 minutes of elapsed irrigation time.

However it should be emphasised here that the effect of microtopography on waterfront pattern is significant in causing the minor deviations between observation and prediction.

Volume balance during advance

Figure A1- 7 shows the comparison of volume predicted by the model and observed in the field during the advance phase. The predicted volume consists of overland and infiltrated volume determined by the model. The observed volume includes both the volume supplied from supply channel and drainage runoff from the upstream basin. The model prediction of cumulative volume during the advance compares very well with the observed values. The departure observed at the end of advance can be explained by the spatial variability of infiltration parameters and soil variability which are not considered by the model.



- Figure A1- 7. Comparison of predicted and observed volume during the advance phase.

Validation of single regular basin model using Parlange infiltration equation

In this section, the capability of the regular basin model with the use of the Parlange infiltration equation is analysed. Infiltration is commonly handled in most surface irrigation models by a time dependent empirical Kostiakov-Lewis equation. However, the empirical parameters of Kostiakov-Lewis equation do not represent the physical characteristics of the soil. In contrast the quasi-analytical Parlange infiltration equation modified by Kaverkamp et al (1990) is based on four parameters depending on soil properties, depth of overland flow and time. The Parlange model is defined as follows:

$$t_{op} = \frac{S^2 + 2h_{str}K_s(\theta_s - \theta_i)}{2\delta(1-\delta)(K_s - K_i)^2}\ln\left[1 + \delta\frac{K_s - K_i}{I_s - K_i}\right] + \frac{K_s(h - h_{str})(\theta_s - \theta_i)}{(K_s - K_i)(I_s - K_s)} + \left[\frac{S^2 + 2h_{str}K_s(\theta_s - \theta_i) + 2(1-\delta)K_s(h - h_{str})(\theta_s - \theta_i)}{2(1-\delta)(K_s - K_i)^2}\right]\ln\left(\frac{I_s - K_s}{I_s - K_i}\right)$$

where S = soil sorptivity ($m/s^{(1/2)}$)

K_s & K_i are saturated and initial hydraulic conductivity respectively ($m.s^{-1}$)

θ_s & θ_I = moisture content at saturation and initial respectively

h_{str}= parameter that takes into account infinite diffusivity near saturation (m)

δ= shape parameter that relates hydraulic conductivity with soil moisture content.

These properties make this equation more appropriate for future use in soil mapping information systems linking infiltration to soil physical characteristics. The use of this equation requires the determination of soil parameters namely saturated and unsaturated hydraulic conductivity, initial and final volumetric soil moisture content, sorptivity and the soil parameters δ and h_{str}. Some of these parameters were obtained by measuring soil moisture before and after the irrigation event and by measuring the basic soil properties in the laboratory and field. Other parameters were obtained from the literature on studies conducted on similar soils in the vicinity of the experiment. The parameters used for the computation of infiltration using Parlange equation are shown in Table A1- 1. The values of initial and final soil moisture were mesured during the field experiments. The values of other parameter e.g. unsaturated hydraulic conductivity K_i, saturated hydraulic conductivity K_s and sorptivity S were taken from the field monitoring study conducted on similar soil in the experimental area (Smith 1999). The values of parameter δ and h_{str} were taken as suggested in Haverkamp *et al*. (1990).

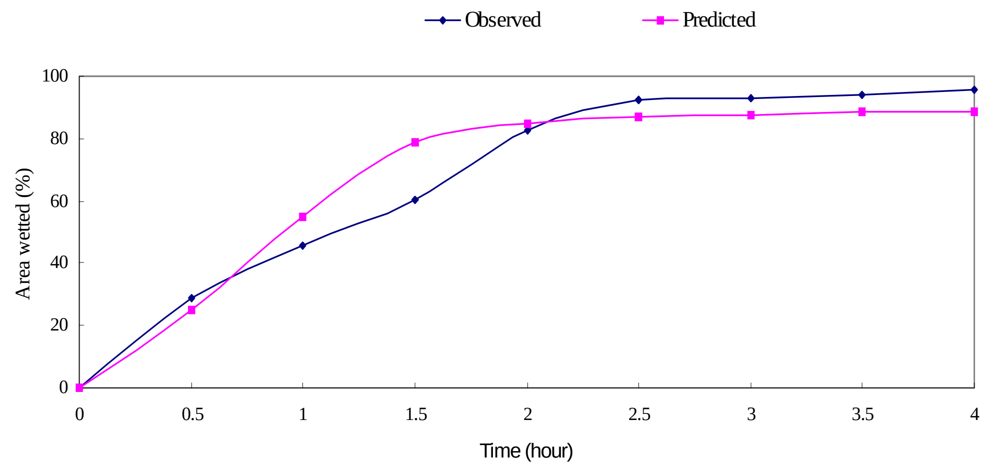
For the validation of the regular basin model with the Parlange infiltration equation, the basin was irrigated with both line and point inflow. The data collected during the second irrigation event of 1998/99 season were used for the validation. The inflow rate, duration of inflow, Manning coefficient and time of simulation were the same as those used in the earlier validation of the regular basin model using the Kostiakov-Lewis infiltration equation combined with line and point inflow.

• Table A1- 1. Values of parameters used with Parlange infiltration equation

Parameter	Value
θ_i	0.38
θ_s	0.47
K_i	5.67 x 10 $^{-16}$ m/s
K_s	2.29 x 10 $^{-6}$ m/s
S	2.64 x 10 $^{-4}$ m/$\sqrt{s}$
δ	0.95
h_{str}	-0.02 m

Area wetted vs advance time

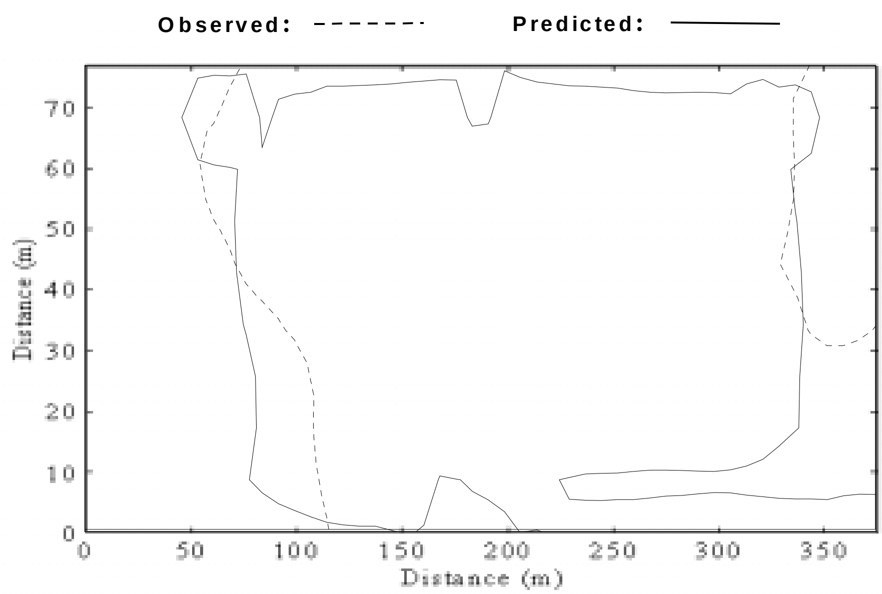
Figure A1- 8 shows the simulated and observed wetted area during advance phase obtained by using the Parlange equation. It can be seen from the figure that model results compare well with the experimental data for most of the advance trajectory. The wetted area predicted by the simulation model using Parlange equation is similar to that predicted with the empirical Kostiakov-Lewis equation. However, the error in predicting the total area after advance phase is 7% compared to 9% in the case of model with Kostiakov-Lewis equation.



• Figure A1- 8. Predicted and observed wetted area for second irrigation using Parlange infiltration equation.

Waterfront advance pattern

Figure A1- 9 contrasts the waterfront advance predicted by the model using the Parlange infiltration equation with that observed in the field after 30 minutes of irrigation. The comparison shows that the predicted advance pattern compares well with the observed pattern of waterfront advance. It must also be pointed out that the results of area wetted and waterfront advance pattern using the Parlange



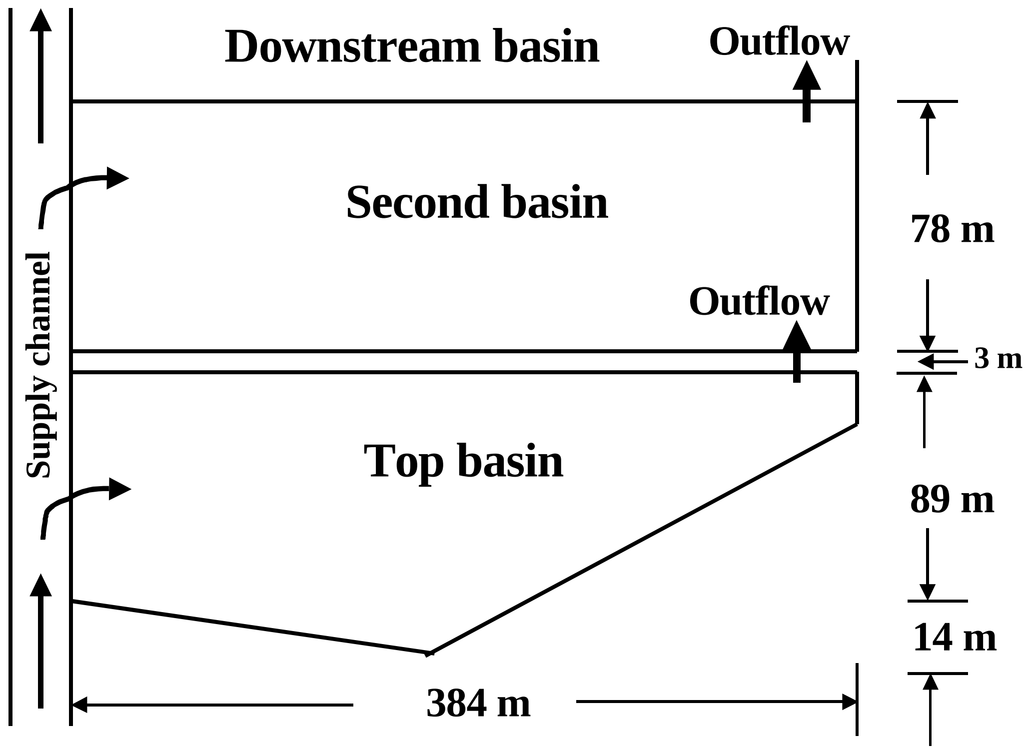
• Figure A1- 9. Waterfront advance pattern after 30 minutes of elapsed time during the second irrigation.

equation are similar to those with the output from model with Kostiakov-Lewis equation in this instance.

Validation of irregular-multi-basin model using Kostiakov-Lewis infiltration equation

The simulation model for irregular shape contour basins was validated for an extended system that incorporates multiple basins. This model also simulates multiple basins of regular shapes as a special case of irregular shape basins. The model can compute infiltration using either the Kostiakov-Lewis infiltration equation or the Parlange infiltration equation. This validation is however limited to the Kostiakov-Lewis equation as the capability of the model to handle the Parlange infiltration equation was demonstrated earlier.

Data collected during the second irrigation of 1999-00 irrigation season was used to validate the model. The layout and dimensions of the two basins is shown in Figure A1- 10



• Figure A1- 10. Multiple basin layout used for model validation

The top basin was irrigated from the supply channel (line inflow) with an average discharge rate of 0.1 m^3/s for a period of 9 hours at the end of which the water supply was cut off and diverted into the second basin. The second basin was irrigated from the supply channel with an average discharge rate of 0.12 m^3/s for 6 hours. The flow rate to the second basin was higher because it included the drainage backflow from the top basin. Drainage runoff from the top basin was also allowed into the second basin through the check bank at an average rate of 0.025 m^3/s.

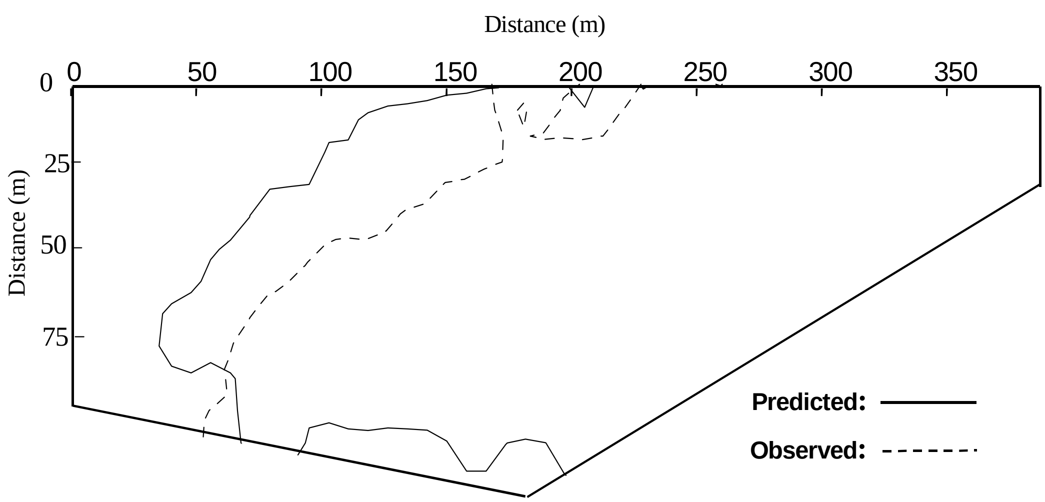
The ground elevations of both basins surveyed on a 12.5 m x 12.8 m grid was used in the model. A Manning coefficient n= 0.17 was used for both basins on the basis that the soil was relatively wet and all the cracks were closed. The infiltration parameters used in the simulation are shown in Table A1- 2. These values are taken from the studies conducted on the similar type of soils in the area (Maheshwari and Jayawardane 1992; Hume 1993).

• Table A1- 2. Kostiakov-Lewis parameters used for model validation

Basin	k **(m/s^a)**	a	b **(m/s)**
Top	0.037	0.03	0.0
Second	0.037	0.021	0.0

Waterfront advance pattern (top basin)

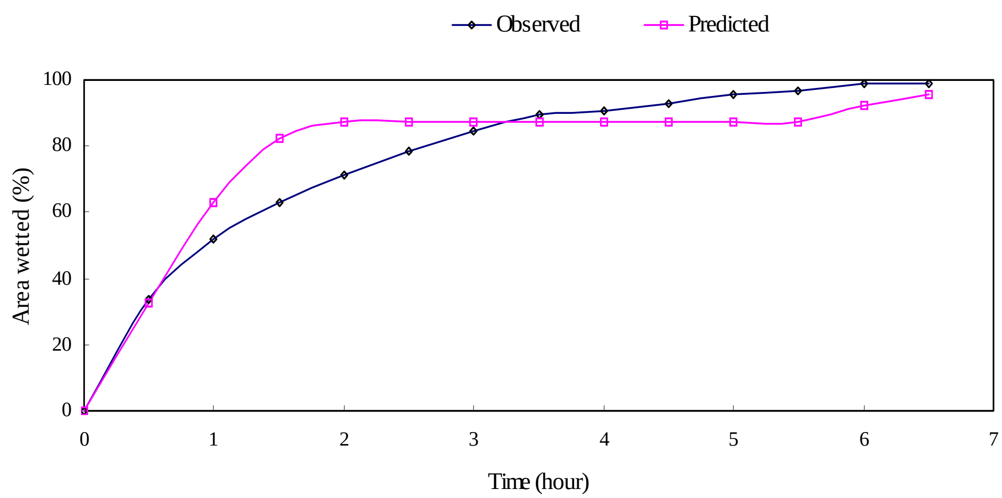
Figure A1- 11 shows the comparison of waterfront advance pattern in top basin after 1 hour had elapsed from the beginning of irrigation. The model predicts waterfront advance with reasonable accuracy over the entire advance contour given the surface irregularities and spatial variation of infiltration.



• Figure A1- 11. Waterfront advance after 1 hour in top basin.

Wetted area (second basin) vs advance

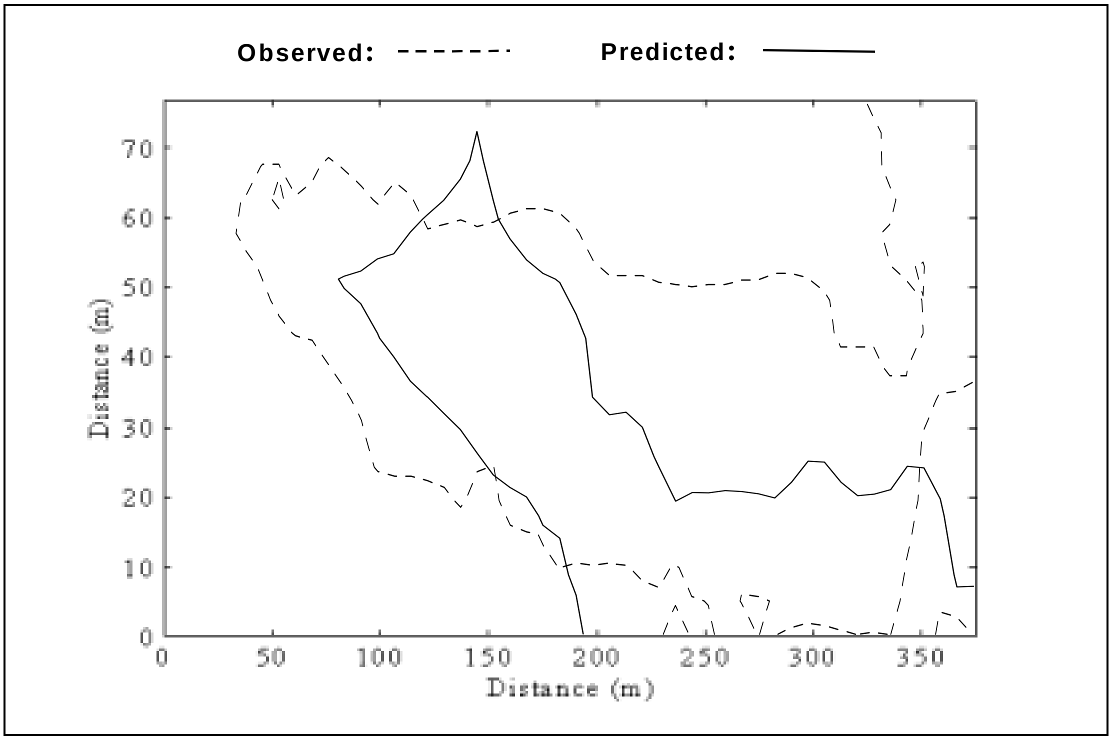
Figure A1- 12 shows the comparison of the cumulative wetted area predicted by the model and observed wetted area during advance phase for the second basin. Water supply was diverted to the second basin from the supply channel together with drainage runoff from the top basin (point inflow) once water had completely covered the top basin. Figure A1- 12 shows that the model is capable of incorporating both types of inflows for the irrigation simulation in the second basin in a multiple basin scenario which includes basins of irregular shape.



- Figure A1- 12. Comparison of observed and predicted wetted area during advance for irregular shape basin (second basin).

Waterfront advance pattern (second basin)

Advance of the waterfront predicted by the model was also compared with observed data to determine the model capability to incorporate line inflow and point inflow in a multiple basin system. Figure A1- 13 shows the comparison of observed and predicted waterfront advance pattern 1 hour after irrigation commenced in the second basin. The match between the observed and predicted waterfront patterns



• Figure A1- 13. Waterfront advance in the second basin after 1 hour.

is good despite of the fact that there were microtopographical variations in both the basins.

Multiple basin water balance

The final water balance for the irrigation event was computed by simulating the behaviour of the composite system comprising both basins. Table A1- 3 shows the summary of predicted and observed water balance in each basin. In both cases the water balance was adjusted by the same evaporation amount given that the model doesn't account for evaporation.

The predicted inflow volume for the top basin matches very closely with the observed volume of inflow. The error in prediction ranges from 0.2% for the first basin to 21% for the second basin. It should be noted here that the observed volume was based on the average inflow measured in the supply channel. The model-predicted inflow volume consists of overland flow and infiltrated volume at the time of shutting off the water supply to the basin.

• Table A1- 3. Comparison of observed and simulated water balance

Parameter	Top basin		Second basin	
	Observed	Predicted	Observed	Predicted
Inflow volume (ML)	3.56	3.57	3.74	2.96
Outflow volume (ML)	2.23	2.17	2.33	1.9
Infiltrated volume (ML)	1.01	1.08	1.11	0.74
Evaporation	0.32	0.32	0.32	0.32

The comparison of infiltrated volume predicted by the model during the irrigation event shows that there is a reasonable correspondence for the top basin while it shows some departure for the second basin. The error in prediction ranges from 7.0% for the top basin to 30% for the second basin.

The outflow volume includes the backflow into the supply channel and the drainage runoff through the check bank into the second basin. In both cases the comparison of outflow volume predicted by the model with the observed values indicates that the model can simulate inter-basin flow with reasonable accuracy.

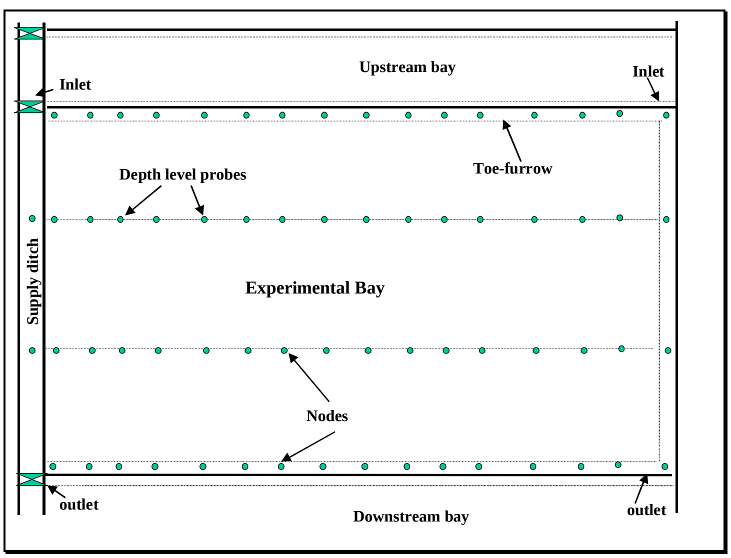
Appendix 2: Field Experiments

Irrigation Trial (1998-99)

The computer model (CoBaSim) developed in this research was verified using the field data obtained from field the experiment conducted on a farmer's commercial layout during the irrigation season. Two irrigation events were monitored during the irrigation season 1998/99. The monitoring techniques used to collect data during the experiments were first tried on a small contour layout (Bay size: 30 X 60 m) located at the NSW Agriculture experimental station, Deniliquin during the 1997/98 season.

The first pre-irrigation trial for the simulation model was conducted on Bill Rumble's farm, at Wyanda near Deniliquin, NSW. The experiments were conducted during the period from 2-3-99 to 18-3-99. Field experiments were carried out with a side ditch layout in which detailed monitoring of waterfront advance and recession, flow depth, inflow and outflow was carried out. The experimental bay used in the study was 384 m long and 78 m wide (2.995 ha) and is currently sown to sub-clover. The basin had been laser levelled in both directions about five years earlier and presented local undulations due to traffic of sheep and machinery.

Figure A3- 1 shows the detailed layout of the experimental bays. The soil properties for the depth up to 45 cm were determined and soil is classified as Riverina-Billabong clay. Soil layers contains 37-60% clay, 17-26% silt and 21-37% sand. The bulk density is in the range of 1,320-1,750 kg/m^3.

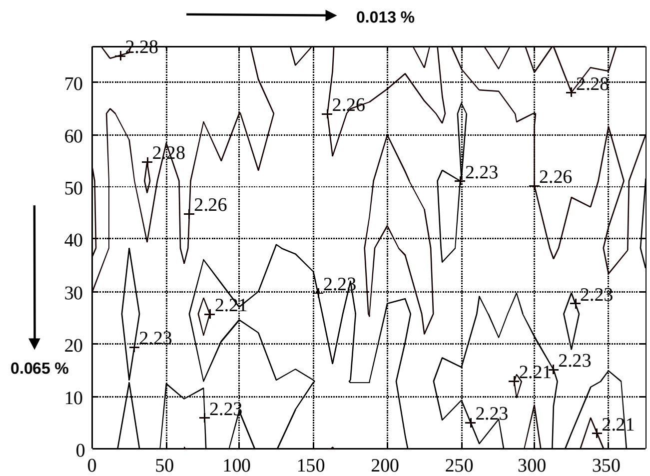


- Figure A3- 1. Layout of the field experiment trial

The contour map of the bay is shown in Figure A3- 2 . The map was obtained from a topographic survey based on a 12.8 m x 12.5-m grid spacing. The bay is flat and the slope is about 0.013% and 0.065% along the length and width respectively. Cups were buried on a 25.6-m x 25-m grid (twice the survey spacing) for placement of DATAFLOW[1] depth probes, which were used to monitor the depth of overland flow. Initial soil samples were collected at two points on the bay to determine the initial moisture content of the soil. Field and grid nodes were mapped using a GPS (Global Positioning System). A total of 69 probes were placed on the bay, toe-furrow and supply ditch for monitoring flow

[1] DTAFLOW is a Trade Mark of Dataflow Systems Pty Ltd.

depth. The GPS was also used to monitor the advance of the waterfront over the field by walking along the waterfront line.



- Figure A3- 2. Contour map of experimental bay

Irrigation was started at the upstream bay and water was later allowed to flow into the experimental bay. Inflow and outflow rates were monitored using Starflow Flow meters installed in the rectangular flumes placed at the inlet and outlet point of the supply ditch. Depth of flow in the flumes at inlet and outlet was also monitored using depth level probes installed in the flumes. Flow velocity at the inlet and outlet in the flume was periodically measured using a current meter to provide backup data in case of failure of the Starflow meters.

The depth probes were removed from the field on the evening of second day for downloading of data. Although water at most field nodes had infiltrated, there was still water in the toe-furrow due to the local microtopography. Final gravimetric soil samples were collected after irrigation to determine the final moisture content.

Recession was very slow as outflow was allowed from only one point back to the supply ditch while in practice farmers allow water to drain into the downstream bay using two outflow points. These points are normally located near the supply channel and the other near the bottom of the basin. Field monitoring of the recession front is less precise because of the furrowing effect of tillage equipment, movement of sheep and small-scale topographical effects.

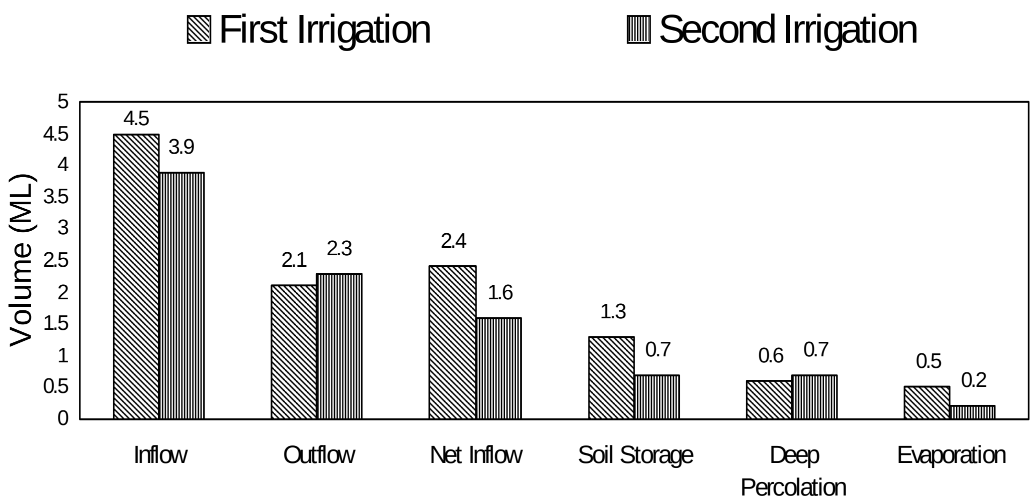
Second Irrigation trial

The second irrigation trial was conducted 10 days after first irrigation. This trial was modified to include an additional drainage outflow point from the upstream bay which is more in line with normal farmer's practice. The inflow and outflow points were fitted with Starflow meters and depth level probes to monitor flow rate and depth. At the time of trial the sub-clover was less than 1 cm high.

Advance and recession were again monitored using a GPS at an interval 5-10 min for advance and at 1 hour for recession. The advance of the waterfront was now faster than the pre-irrigation trial as the soil was wet and cracks in the soils had closed. The advance of the waterfront was completed in 4 hours as compared to 8 hours in first trial. Another reason for the faster completion of advance phase was the additional point inflow on the side ditch. The recession phase was also monitored by the of depth level probes installed at the grid nodes. This resulted in better recession data than the GPS survey.

Water balance

A water balance was carried from data collected during the first and second irrigation trial for experimental bay. These included inflow, outflow and soil moisture status before and after irrigation. Details of the volumetric inflow, outflow, net inflow, soil storage, deep percolation and evaporation during first and second irrigation are shown in Figure A3- 3.



- Figure A3- 3.. Water balance for the irrigation events during 1998-99 trial

The water balance figures indicate that inflow to the basin during the second irrigation is reduced by 13% despite the additonal drainage water received from the upstream bay. The reason for this reduction was due to comparatively wet soil and less cracking leading to faster advance of the waterfront. Outflow from the basin was about 50 % of the total inflow. It was higher (59% of inflow) during the second irrigation due mainly to the additional drainage outlet on the side of the basin.

Net inflow (Inflow-outflow) was used for soil storage, deep percolation and evaporation. The water available as net inflow during the second irrigation was 33% less than in the first irrigation. Soil storage during both the irrigation events was nearly same although soil during second irrigation was wet compared to first irrigation. This indicates that large amounts of water were lost to deep percolation. This is indicated by the deep percolation amount during the second irrigation, which was 15% higher than the first irrigation. It also indicates that the basin was over-irrigated. The basin was not sufficiently drained despite the extra outflow point. Evaporation during the second irrigation was observed to be less than half as compared to the first irrigation indicating a shorter irrigation event.

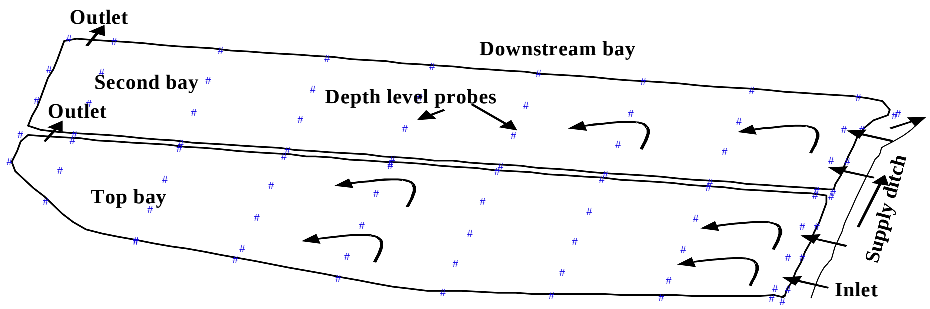
Irrigation Trial (Multiple basins, 1999-00)

An irrigation trial was conducted during the season 1999-00 on the same field. The objective of this trial was to collect data for verification of an extended version of simulation model, which included multiple irregular shape basins. The field experiment was conducted to monitor the irrigation events in the first two basins of the irrigation block (five bays) instead of the single bay monitoring conducted during the year 1998-99. The first basin of the irrigation block is of irregular shape (top bay) while the second bay is of rectangular shape.

Inter basin drainage discharge at the outlet point was monitored during the trial. In addition, detailed monitoring of inflow, outflow, soil moisture status, advance and recession of waterfront and evaporation was conducted. The layout of the irrigation monitoring trial is shown in Figure A3- 4. This figure shows the detailed layout of the bays (top bay, second bay), location of supply ditch, inlet and outlet points, and inter-basin flow direction. The figure also shows the nodes depicting the location of depth level probes installed for monitoring the overland depth of flow. The irrigation events were monitored during the period between 14-03-00 and 6-04-00. Two irrigation events were monitored.

First irrigation

The monitoring of the first irrigation event was conducted during the period from 14-03-00 to 17-03-00. The farmer had cleaned and broadened the toe-furrows of all the bays in the irrigation block following our request. A topographic survey was conducted on both bays on a grid size of 12.5 x 12.8-m.



• Figure A3- 4. Layout of experimental multiple basin system.

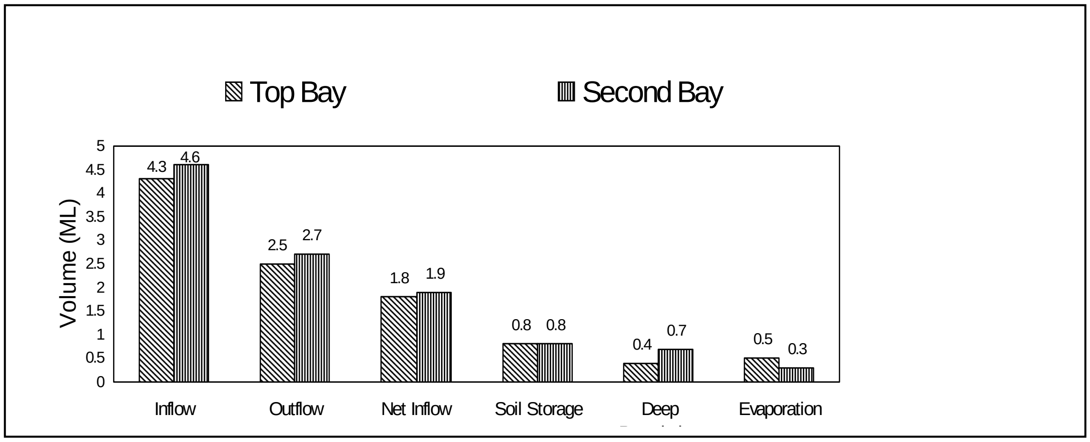
including the bay boundaries which were mapped with a GPS. Due to the limited numbers of depth level probes available, the grid size for monitoring the overland flow depth was increased to 25.6 x 50 m in both bays. Overland flow depths were monitoried with water depth probes placed in cups buried at the grid points.

An initial soil moisture survey was carried out on a 25 x 25 m grid using a mobile soil moisture monitoring unit fitted with TDR probles. Because of the dry soil, it was very difficult to drive the soil moisture probe past a depth of 15 cm. Evaporation was recorded for the period of irrigation which lasted 49 hours by placing a pan evaporimeter in the top bay.

Discharge in the supply ditch was monitored with a Starflow meter installed in the entrance pipe in addition to the flow meters set in the rectangular flumes. The drainage outflow from the top bay was also measured with a Starflow meter.

Water balance of first irrigation

Based on the information collected, and soil parameters of the experimental area, water balance of first irrigation of top and second bay was conducted. Figure A3- 5 shows the volumetric quantity of inflow, outflow, net inflow, soil storage, deep percolation and evaporation. Net inflow in the figure shows the difference between inflow and outflow. Soil storage was taken to a depth of 15 cm below ground as pre-irrigation soil moisture status was also conducted to 15 cm. Figure **Error! Reference source not found.** indicate that inflow to the second bay was higher compared to the top bay. However, net inflow and soil storage was almost same for both the bays.



- Figure A3- 5. Water balance of first irrigation for both bays

Figure A3- 5 shows that outflow from both the bays were almost 60% of inflow. It can be observed that the drainage from the basin was better as compared to drainage in the first irrigation of the season 1998-99. Drainage occurred through both the check bank into the second basin as well as to supply channel. The reason of faster drainage is due to a cleaner and wider toe-furrow and the additional point of outflow located through the check bank.

Deep percolation losses during the first irrigation were 24% and 36% of net inflow for the top and second bay respectively. This deep percolation cannot be termed lost water as soil storage was only computed for the top 15 cm of soil depth. Part of this water was also used for soil saturation and filling the soil cracks.

Second irrigation

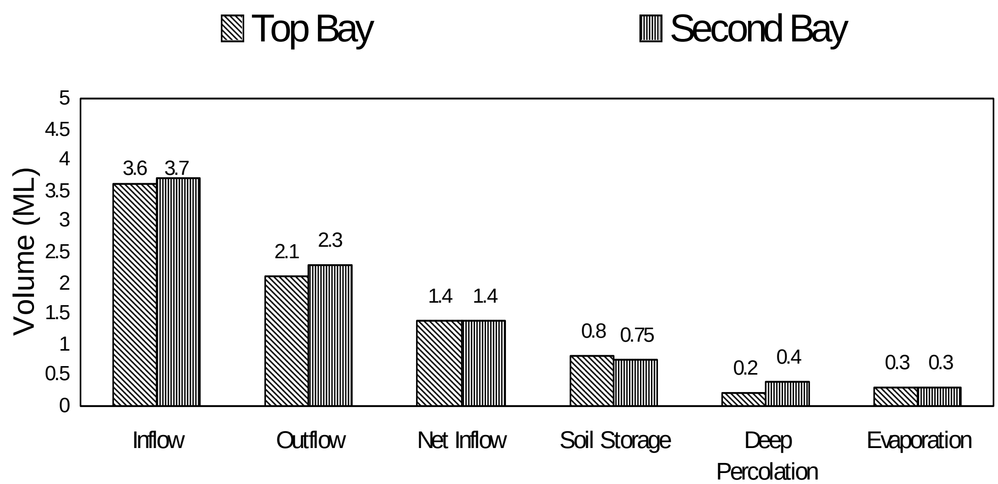
The second irrigation was carried out 20 days after the first irrigation. This irrigation was considered a within-season irrigation in which the soil was not as dry as in the first irrigation and the cracks were almost completely closed. The sub-clover was germinated and had grown to about 2-3 cm long. Pre-irrigation soil moisture status was determined using gravimetric sampling in both bays up to the depth of 45 cm. For water balance purpose however, only the top 30-cm soil layer was considered.. During this event irrigation advance was faster compared with the first irrigation due to relatively wet and cracked filled soil requiring 30 hours to complete the irrigation of the five bays.

The layout of the experiment and monitoring devices were the same as that of first irrigation. The inflow to top bay was smaller (about 16 %) than the first irrigation.

When the top bay was entirely inundated, water was supplied to the second bay from the supply ditch and from the top bay drainage outlet. Waterfront advance over the second bay lasted for about 6 hours requiring about 19 per cent less inflow than in the first irrigation.

Water balance after second irrigation

The water balance for both the bays was calculated in the same manner as of first irrigation and shown in Figure A3- 6



- Figure A3- 6. Water balance of both bays after second irrigation

The water balance figures indicate that the net inflow and soil storage for both bays was same. However, deep percolation in the top bay was 15% of the net inflow which was less than deep percolation in the first irrigation. This could be due to the fact that soil moisture storage was considered for the top 30-cm soil and to better drainage. This was also observed in the second bay in which deep percolation was 25% of net inflow.

Discussion on water balance

A water balance for each irrigation event was calculated to determine the performance of the experimental basins and to later use it to validate of the computer simulation model. A common feature of both irrigation events was the large amount of deep percolation losses. The main factor causing over-irrigation and loss of water to deep percolation is slow drainage.

Poor drainage leading to over-irrigation is an important factor in the management of contour basins. There are many reasons for the improper drainage of the basin, including microtopography of the basin, poorly maintained toe-furrows, size and number of outlets and excess water application.

The microtopography of the contour basin is a critical factor that affects advance and recession of the waterfront. Although the experimental basin was laser graded about 5 years ago, it now has local undulations due to sheep tracks and vehicle traffic. This causes local stagnation of water and poor water movement. It is necessary to maintain the basin and remove local undulations regularly in order to improve the overland water movement and reduce ponding time.

Toe-furrows are the key to efficient drainage of the basin. They should be as large as practical and properly graded. They must be maintained clean and free of obstructions. The toe-furrows of the experimental basins were not clean and had a large amount of dry grass during the first year. This caused high roughness and impeded the smooth flow of water. It was also observed in the 1998/9 season that large amount of water stagnated in the toe-furrows. The effect of clean and wide toe-furrow was observed in the season 1999-00, when all the toe-furrows were cleaned and widened prior to irrigation. This reduced the deep percolation losses in the second basin almost by half compared to the losses during the 1998/99 season with uncleaned toe-furrows.

Another factor that affects the drainage of contour basins is the size of outlets used to carry drainage water. During the first irrigation trial, drained water was allowed back into the supply ditch but no additional outlet was used on the sides of the basin. An additional outlet was used in the second irrigation. The size of the outlet however limited the potential drainage improvement and reduction of ponding time.

Appendix 3: Design and management guidelines

The main objective of developing a computer simulation tool is to enable users to simulate the behaviour of multiple design scenarios. This requires the application of the model to each design case using the specific geometric configuration and design data for the system concerned. In this chapter, the model is used to explore in general the effect of some design parameters on the performance of contour basins. The main aim of this analysis is to provide designers and practitioners with an overall view of the likely impact trends arising from these design factors. It is not intended to replace the specific analysis needed for each individual design problem using the computer model CoBaSim.

The following parameters are considered in this analysis:

- Aspect ratio: ratio of width to length of the basin
- Longitudinal slope
- Elevation difference between basins
- Local micro-topography
- Number of drainage outlets

All these parameters are studied by setting up a hypothetical design situation somewhat typical of the dimensions and parameters encountered in commercial layouts.

The effect of these design parameters on irrigation performance is measured by the time of advance needed to cover the entire basin area and the effect on irrigation efficiency and uniformity. These are measured by:

- Application efficiency
- Water requirement efficiency; and,
- Distribution uniformity.

Application efficiency is typically defined as follows (Burt et al, 1997):

$$Application\ efficiency = \frac{\begin{array}{c}Average\ depth\ of\ irrigation\ water\\ contributing\ to\ target\ depth\end{array}}{Average\ depth\ of\ irrigation\ water\ applied}x100$$

In this definition the average depth of irrigation water applied is the total volume of inflow during an irrigation event. Because of the particular features of basin irrigation in South East Australia where drainage usually occurs following the cessation of inflow, this term must be redefined to take into account the drainage runoff occurring as backflow at the inlet end and through the check bank between basins. The computer model calculates 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):

$$Water\ req't\ efficiency = \frac{Average\ depth\ stored\ in\ root\ zone}{average\ depth\ of\ potential\ storage} x100$$

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 is measured by Distribution Uniformity which is defined as follows (Burt et al, 1997):

$$Distribution\ uniformity = \frac{Average\ low\ quarter\ depth}{Average\ depth\ of\ irrigation\ applied} x100$$

The average low quarter depth is the average depth of water applied to the 25% of the field receiving the least amount of water.

Effect of aspect ratio

A single basin 200 m long was selected for the analysis of aspect ratio. The width of the basin is varied between 60 m and 200 m to provide a range of aspect ratios between 0.3 and 1.0.

The following design parameters were used in the simulation:

Inflow rate per unit width: 0.0018 $m^3/s/m$

Infiltration parameters: k=0.055 $m/s^{0.026}$; a=0.026; b=0.0

Manning roughness (n) = 0.05

The topographic elevations of the experimental basin were used for this simulation.

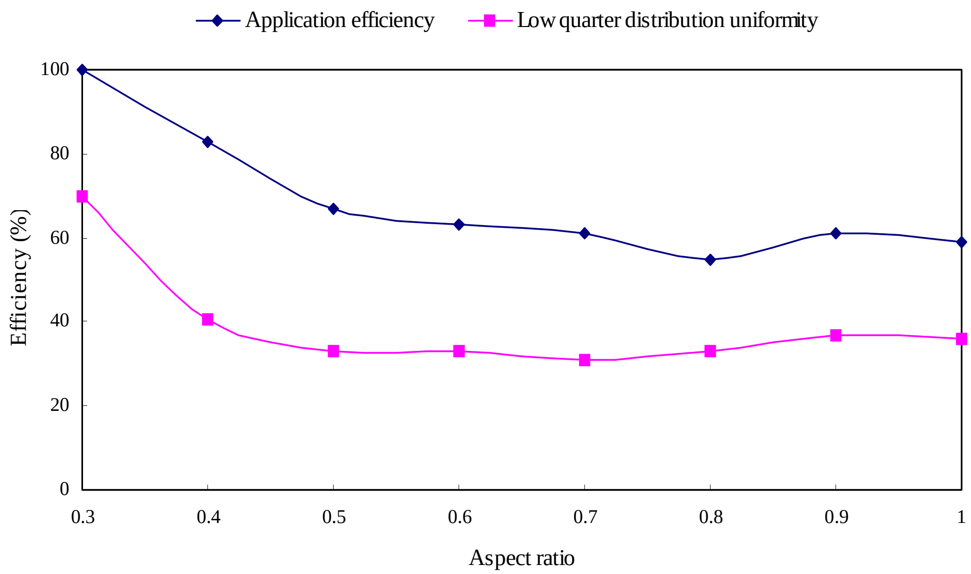
In all cases the model was run for a simulation period of 7 hours.

Advance time

Figure A3 - 2 depicts the effect of changes in aspect ratio on the time of advance. There is a significant increase in time of advance with an increase in the width of the bay despite the inflow discharge increasing in proportion to the basin width. 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 time of advance. This increase in the time needed to flood the basin has a significant effect on the amount of water applied and potentially on irrigation efficiency given that a small depth is required in each application for the typical crops grown in these basins.

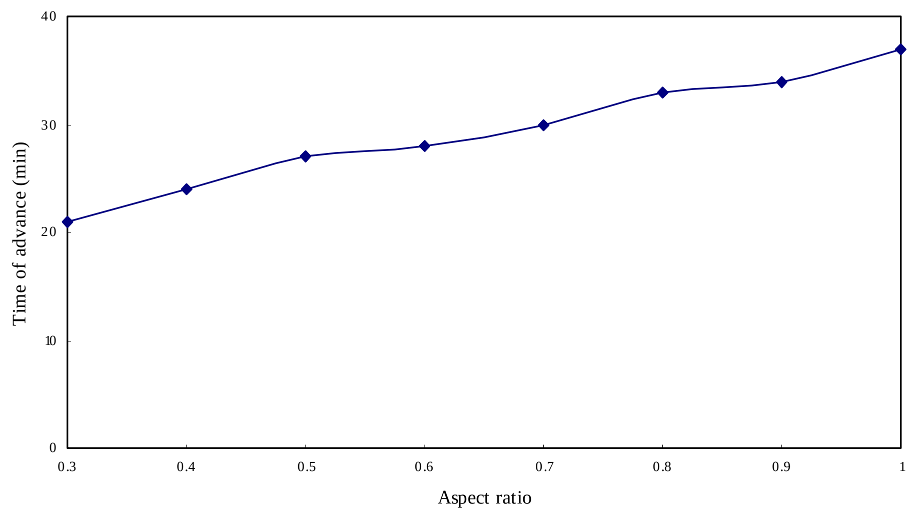
Efficiency and uniformity

Figure A3 - 1 illustrates the effect of aspect ratio on the behaviour of application efficiency and distribution uniformity. Application uniformity decreases as the aspect ratio approaches 1.0 (square basin). This is consistent with the fact that an increase in advance time leads to greater deep percolation losses.



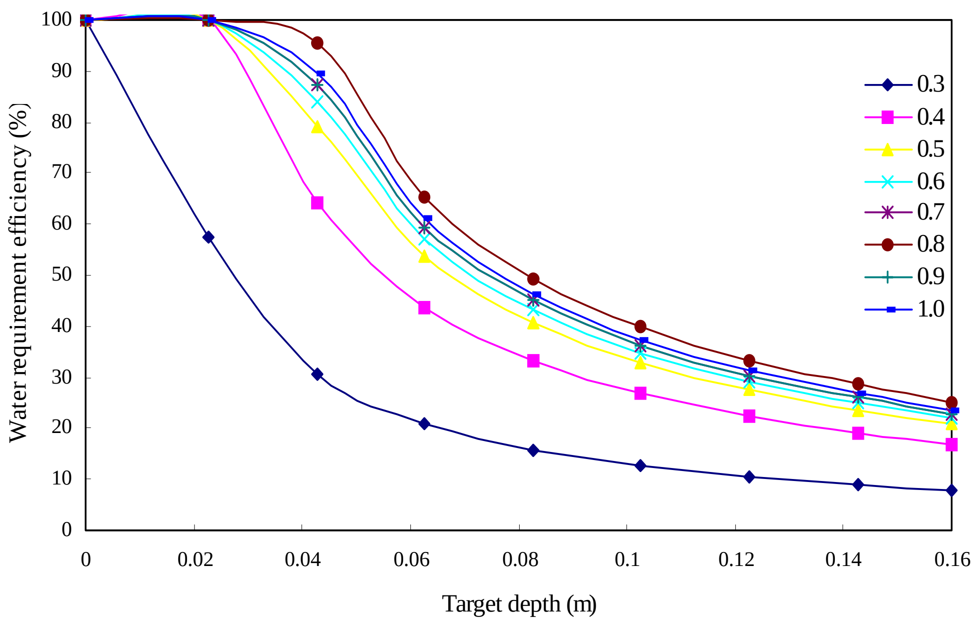
- Figure A3 - 1. Effect of aspect ratio on application efficiency and distribution uniformity.

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.



- Figure A3 - 2. Effect of aspect ratio on time of waterfront advance.

Figure A3 - 3 shows that the ability to apply the target depth over the entire basin area depends on aspect ratio. As the width of the basin decreases in relation to its length the amount of underirrigated area increases. The sensitivity of this parameter to aspect ratio appears to be higher for low aspect ratios than for high aspect ratios, e.g. approaching square basins. This follows a opposite trend to application efficiency, thus reinforcing the need to careful analysis in each design case.



- Figure A3 - 3. Water requirement efficiency variation with target depth for different aspect ratios

Effect of advance slope

Basins are by definition irrigation units levelled 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 hypothetical basin 200 m in length and 200 m wide is used to determine the effect of slope in the advance direction. The basin topography was assumed to follow a regular elevation plane with local irregularities. Several simulation runs were carried out varying the advance slope between 0.03% and 0.08% to include the typical slopes used by irrigation designers.

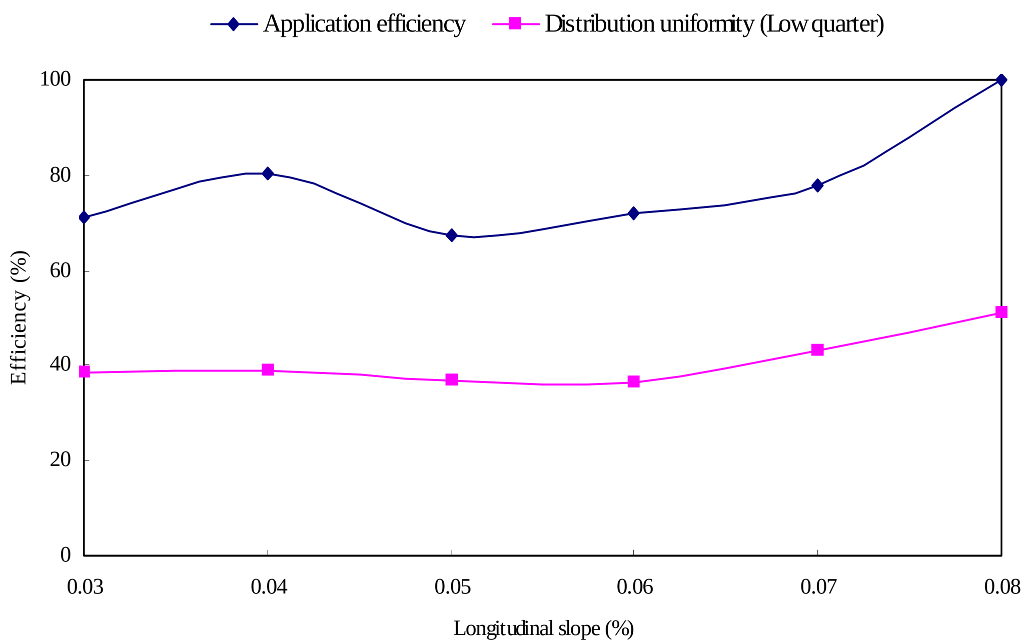
The design assumptions used for this analysis are as follow:

- Water supply: Line inflow (top basin) q=0.015 $m^3/s/m$
- Grid size: 10 m x 10 m.
- Infiltration parameters: k=0.055 $m/s^{0.026}$, a= 0.026; b= 0.0

- Duration of inflow: Until completion of water front advance over the entire basin.

- Duration of simulation: 14 hours

Figure A3 - 4 depicts the effect of slope on application efficiency and distribution uniformity. Both parameters show improvement as the slope increases within the range normally encountered in common design practices among designers. 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.



- Figure A3 - 4. Application efficiency and distribution uniformity as a function of advance slope.

Effect of contour interval in multiple basin systems

The vertical difference in elevation between contour basins is primarily dictated by the land topography. Through land forming practices however designers can provide different elevation intervals between adjacent basins. A two-basin layout was selected to analyse the effect of contour interval on irrigation performance. The topography of the top basin was assumed to be the same as that of the experimental basin used in this research. The same topography was replicated for the second basin for differences in vertical displacements ranging between 0.05 m and 0.15 m.

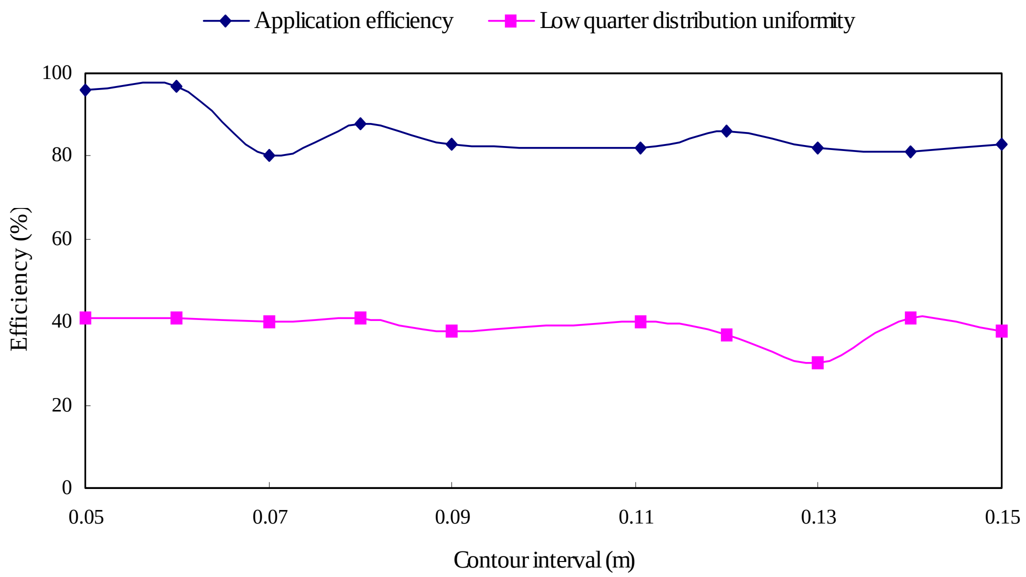
The following dimensions of the system and design parameters were used in the analysis:

- System size: 2 basins 200 m x 100 m

- Water supply: Line inflow (top basin) q=0.015 m^3/s/m

- Line inflow & side drainage runoff (second basin)
- Grid size: 10 m x 10 m.
- Infiltration parameters: k=0.055 m/s$^{0.026}$, a= 0.026; b= 0.0
- Duration of simulation: 14 hours

The effect of vertical basin elevation difference between basins on distribution uniformity and application efficiency is shown in Figure A3 - 5 Overall application efficiency and distribution uniformity show a slight decreasing trend with increased vertical difference in elevation between basins albeit the relation is largely insensitive. This would suggest that an increase of contour interval does not cause significant increase in drainage ouflow and the flow behaviour in both basins is independent to each other. This relation suggests that there are no significant benefits to be gained from increasing the vertical difference between basins unless this is a natural consequence of the natural topography.



- Figure A3 - 5. Application efficiency and distribution uniformity for various vertical contour intervals between basins.

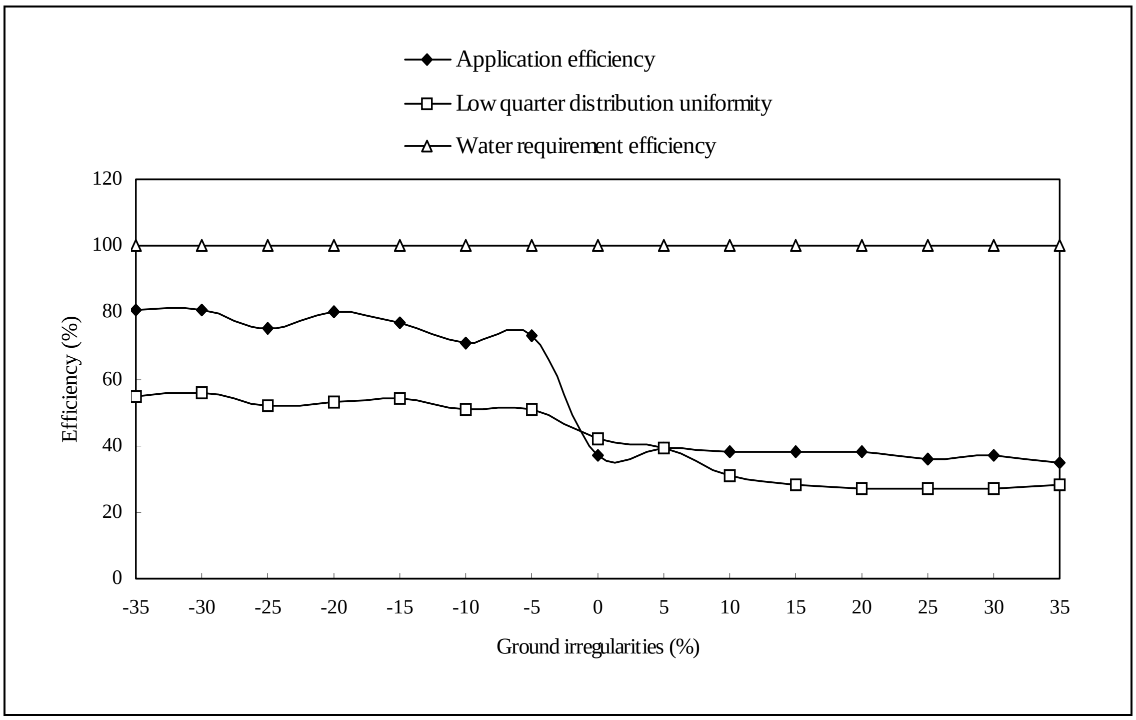
Effect of Local Microtopography

Local undulations on the basin's surface are know to significantly affect advance and recession of the waterfront (Walker & Skogerboe, 1987) and irrigation performance. These undulations are present in laser-levelled basins and are the result of machinery and animal traffic. They cause local ponding of water which becomes very important in irrigation basins which are designed with very small or zero slopes.

A 300-m long by 100-m wide basin discretised on a 10 m x 10 m grid was used to analyse the effect of microtopography. The topography of the experimental basins was used for the analysis. The average slope of the basins was determined by the "Plane method" (Walker & Skogerboe, 1987). The deviations between the ground elevation and plane elevations were then determined and used as the baseline values for the sensitivity analysis. These deviations were then contracted and expanded by between 5% and 35%. The remaining simulation parameters were as follows:

- Inflow rate per unit width q=0.00135 $m^3/s/m$
- Infiltration parameters: k=0.055 $m/s^{0.026}$; a=0.026; b=0.0 m/s
- Manning's roughness coefficient n=0.05
- Duration of inflow: until completion of waterfront advance
- Duration of simulation : 10 hours

Surface undulations affect both efficiency and uniformity as shown in Figure A3 - 6. An increase in local undulations leads to a decrease in irrigation efficiency and distribution uniformity. In this analysis, the water requirement efficiency was also determined for the whole range of surface irregularities in order to ensure that a complete irrigation was attained in all cases as shown in Figure A3 - 6. Irrigation efficiency decreased by 40% with an increase in ground surface irregularities of 35% over the natural condition of the experimental basin. This would suggest that laser levelled basins need to be regularly maintained to reduce surface irregularities.



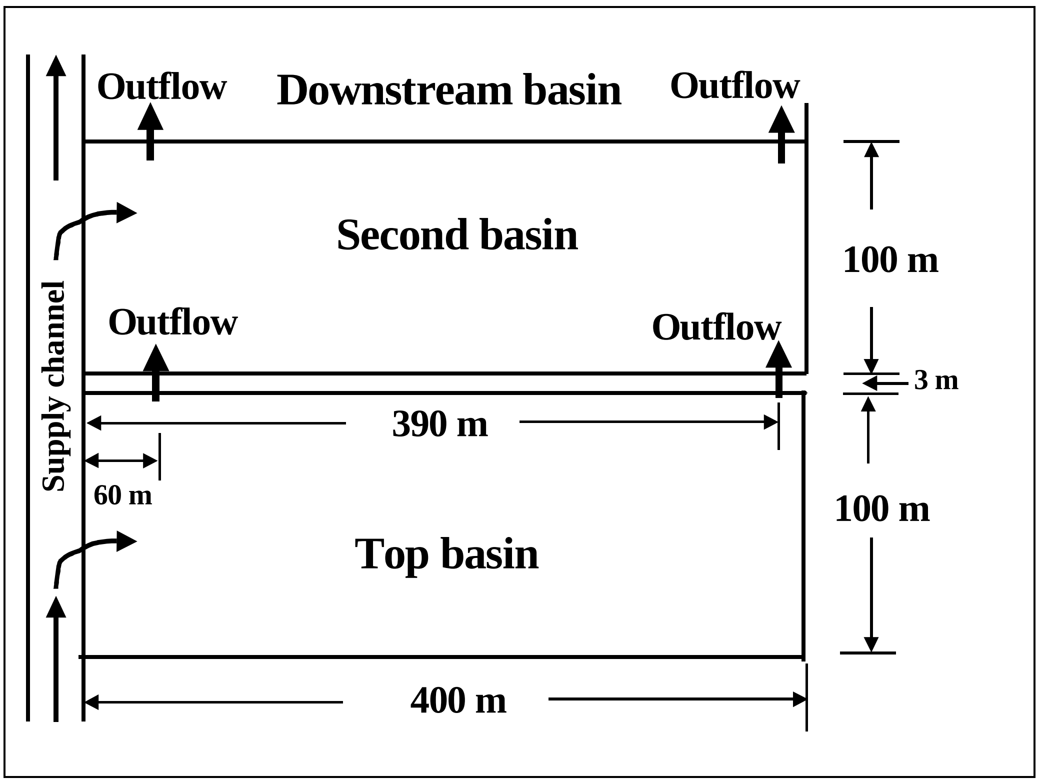
• Figure A3 - 6. Effect of surface irregularities on efficiency and uniformity.

Effect of number of outlets between basins

It is a common practice in the design of contour basins to allow for surface runoff between basins after the inflow to the upper basin has ceased. This is achieved by constructing gated outlets in the check bank between the basins.. This section is aimed to analyse the effect of the number of outlets between adjacent basins on performance.

Two hypothetical basins 400-m long by 100-m wide were selected for this analysis as shown in Figure A3 - 7. In the simulation, inflow to the top basin was assumed to occur only from the supply channel. The two simulation scenarios used in the analysis considered in one case a single drainage outlet located 390 m from the supply channel, and in the second case an additional outlet located 60 m from the supply channel. The remaining simulation parameters were as follows:

- Inflow rate per unit width q= 0.00135 $m^3/s/m$.
- Grid size: 10m x 10m
- Infiltration parameters: k=0.055 $m/s^{0.026}$, a=0.026; b=0.0 m/s
- Manning roughness n=0.05
- Duration of inflow: Until completion of advance
- Duration of simulation: 24 hours



• Figure A3 - 7. Layout of multiple basin system

Table A3-1 contains a summary of the main performance parameters obtained from the simulation. Overall the number of outlets an effect on the time of advance for the second basin which was reduced by 13%. Application efficiency and distribution uniformity of the second basin improved when two outlets were used. This can be ascribed to faster drainage of the overland flow when two outlets are in operation. The effect of using a second outlet was greater on distribution uniformity (11%) than on application efficiency that was only marginally affected. Overall, it can be concluded from this analysis that using a second drainage outlet between basins has a positive effect on the uniformity and efficiency of application mainly due to improved drainage of the upper basin and faster advance in the lower basin.

- Table A3- 1. Irrigation efficienty and uniformity for one and two outlets between two basins.

Number of outlets	**Time of advance (min)**		**Application efficiency (%)**		**Water requirement efficiency (%)**		**Distribution uniformity low-quarter (%)**	
	Top	**Second**	**Top**	**Second**	**Top**	**Second**	**Top**	**Second**
One	68	141	100	98	92	100	81	77
Two	68	123	100	100	92	100	81	88

Appendix 4: COBASIM USERS GUIDE

Appendix 4: Project publications

Khanna, M., H Malano & H Turral. 2000. Performance of Contour Basin Irrigation Layouts in Cracking Soils in South East Australia. Proceedings of 2000 National Conference and Exhibition "Water-Essential for Life" Pp 332-338.

Khanna, M., J Fenton, H Malano & H Turral. 2000. Two-Dimensional Simulation Model for Contour Basin Layouts in South East Australia. Proceedings of Watershed Management & Operations Management 2000. American Society of Civil Engineers. ISBN- 0-7844-0499-2.