A review of Basin (Contour) Irrigation Systems I: Current design and management practices in the Southern Murray-Darling Basin, Australia

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March 2008
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CRC for Irrigation Futures

CRC for Irrigation Futures Irrigation Matters Series No. 01-1/08
March 2008
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Reports in this series

This is a pair of reports aimed at improving the performance of basin (contour) irrigation systems in the Southern Murray-Darling Basin:

1. A review of Basin (Contour) Irrigation Systems I: Current design and management practices in the Southern Murray-Darling Basin, Australia
2. A review of Basin (Contour) Irrigation Systems II: Research needs for evaluation and design

These reports are available from the web at http://www.irrigationfutures.org.au
Foreword

There are at least eight different types of basin layout currently in use in the Southern Murray-Darling Basin. These variants have been designed to accommodate different water supplies, crops, soils, machinery and management styles. However, there is little guidance available as to the benefits of any one of these systems over another. Thus farmers have been left to undertake their own experimentation. The aim of this exercise has been to collate our existing understanding of basin (contour) irrigation systems in the Southern Murray-Darling Basin areas and make this available to anyone with an interest, whether farmer, agency staff or academic. This has been undertaken as:

1. Description and analysis of current layouts
2. Collation of existing data
3. Analysis of previous research
4. Determination of research needs

This work has tried to shed some light on our current understanding of these designs and where we need to invest research effort. The first report looks at the current practices. The second report looks at the research needs to evaluate current layouts and provide appropriate designs. We hope that this review material will be useful to anyone seeking to understand this type of irrigation system and promote much needed research into this area.

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Tools for Irrigation Profitability and Longevity project
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Definitions

Following Walker & Skogerboe (1987), basin irrigation systems are defined as surface irrigated areas which have no longitudinal slope and complete perimeter dikes to pond water and prevent run-off. These are differentiated from border irrigation systems which have slope in the longitudinal direction and free draining conditions at the lower end. The U.S. Natural Resources Conservation Service (1997) National Engineering Handbook differentiates between three principal surface irrigation systems: level, graded and contour. Graded systems are those where water flows in the direction of the land slope. Adapting the nomenclature and definitions in these sources, basin systems in southern NSW can be differentiated into:

1. Contour systems - have slope in the lateral direction (i.e. across the width of the bay) but not in the longitudinal direction (i.e. down the length of the bay). They can be classified as either:
   a. Natural contour systems if check banks follow the natural contour. Laser grading to remove reverse grades may have been conducted within bays.
   b. Parallel contour systems if they have been land-formed so that the check banks along the contour are parallel to each other.

2. Level systems - are completely level within each irrigation bay (i.e. no slope in either longitudinal or lateral directions) and the bays are generally rectangular in shape with a bench (or terrace) between them. They can be classified as either:
   a. Level basin systems are used for growing rice “on the flat” and in rotation with pastures and winter cereals in a mixed farming enterprise
   b. Level furrow systems are used for growing row crops on “hills” or raised beds in a cropping enterprise and are not generally suited to pasture production.

The terms side ditch and bankless channel are used synonymously in this document. Swinton (1994) defined them as a supply channel, running with the slope down one side of an irrigation block and which does not have a bank on the inside of the bay. Checks are placed across the channel at each contour bank to control flows. The bed of the channel is below bay level and it acts as both supply and drain.
Executive Summary

- Basin systems are well suited to the flat terrain and slowly permeable soils of the gravity irrigation schemes in southern NSW. Their principal advantages are their relatively low capital cost, low labour requirement and the high yields, low production risk and high returns per ha for rice.

- Their principal disadvantage, also due to soil type and slope, is their propensity to waterlog. This limits achievable returns per ML, restricts cropping diversity and makes capital expenditure for improvement risky.

- 43% of the Berriquin Irrigation District and 73% of the Wakool Irrigation District is considered poorly drained. Losses due to waterlogging in the Murray Irrigation districts are estimated to be roughly $80 million in a wet year.

- Waterlogging in basin systems occurs as a result of two different but related events:
  1. excessive irrigation opportunity times (the time available for water to infiltrate the soil) due to slow advance and recession rates
  2. inadequate drainage following periods of excess rainfall due to limited soil water storage, low saturated hydraulic conductivity and slow surface drainage rates.

- Four strategies are suggested for improving the irrigated productivity of areas with flat slopes, high clay content and high sodicity: dedicating areas for permanent rice growing; improving drainage using raised beds or spinner cuts; applying gypsum; and improving soil management by restricting traffic, minimising tillage and retaining stubbles.

- The profitability of basin systems may be increased by:
  a. the adoption of controlled traffic, reduced tillage, stubble retention and precision guidance. Increases of 20-30% have been reported but no local studies comparing the operational efficiency of alternative basin designs were found.
  b. better and more flexible irrigation systems which allow the crops returning the most per ML to be selected. A possible increase in gross margins of 100-120% has been reported.

- There is evidence that the irrigation efficiency of contour basin systems may be increased from 55-60% to 80-90% and U.S. experience suggests that the average irrigation efficiency of drain-back level basins is 85%. However, the irrigation efficiency of typical basin systems in southern NSW has not been measured.

- The irrigation efficiency of basin systems will be improved by:
  1. Increasing advance rates - Advance rates are primarily influenced by inflow rate, the surface storage volume, antecedent moisture content and final infiltration rate. Surface storage volume is a function of bay size and the minimum ponded depth. Anything that speeds advance will reduce opportunity times and improve distribution uniformity and irrigation efficiency. There are two main options: increase the inflow rate and/or reduce the required surface
storage volume. Surface storage volumes are minimised by reducing bay size, laser grading to remove reverse grades and high spots, reducing the slope of the bay and adopting furrow irrigation. Other options to speed advance include larger toe furrows and the use of spinner cuts. Slope in the advance direction and surface roughness have only a minor effect on advance.

2. Decreasing recession times
   a. Drainage of excess rainfall - The ability to shed excess rainfall is determined by recession rates off the bay. This is primarily influenced by the slope and surface roughness of the bay and the down-slope distance to a drain (length of run). Winter drainage will be improved by increasing the slope (>1:2000), laser grading, sowing parallel to the direction of water flow, narrower bays, furrow irrigation or spinner cuts in the bay, and larger toe furrows (including side-ditch).

   b. Drainage of irrigation water - The ability to drain quickly following irrigation is influenced by the drainage rate off the bay, the volume of surface storage to be drained, the outflow rate from the bay, and the advance rate and ponded depth downstream of the bay being drained. Irrigation recession time is decreased by reducing surface storage (smaller bays, flat bays, laser grading, furrow irrigation), increasing the number and size of outlets, and individually draining each bay into the farm drain/recycle system. The likelihood of side-ditches being effective depends on the interaction between surface storage volume and paddock slope. They are more likely to be effective in terraced layouts.

• Current “best practice” design recommendations for contour basin systems are generally accepted and widely adopted and there is good recognition of the factors which contribute to poor productivity, particularly soil type and waterlogging. However, design recommendations are nearly 20 years old and do not provide guidance on the design, efficacy and benefit-cost ratio of recent changes such as high flow rates, side ditches, terraces, larger toe furrows and level furrows. Overseas criteria and experience may be applicable to level basin systems in southern NSW and adaptable for level furrow systems, but not contour basin systems.

• General indicators of good design were found to be:
  o Flow rates of 15-20 ML/day
  o Slope greater then 1:2000 for winter drainage
  o Bays less than 400 m long and check banks at a 50 mm contour interval
  o Time for water on for winter crops = 4-6 hours
  o Bays individually supplied and drained into a farm drain
  o Laser graded bays and drainage recycling
  o Cross-overs into bays for access

As a rule of thumb, irrigation designers recommend that bay size in ha should be roughly a quarter of the flow rate in ML/day if a single irrigation uses 1-1.5 ML/ha.
To prevent irrigation induced waterlogging losses, it is recommended that bays be covered by water in less than half the opportunity time. Recommended opportunity times range from 8 to 24 hours, but agronomic data to support this for most crops was not found. Furthermore, this recommendation does not take into account the length of time it takes for a soil to return to aerobic conditions following the cessation of drainage and there is evidence to show that this differs with soil type (duplex soil < heavy clay < sodic soil).

Approximately half the irrigated area in the Murray LWMP area is laid out to contour basin systems. Of this area, half is still in traditional natural contour systems which have not been laser graded. Given this, and the fact that irrigators reported opportunity times roughly double the recommended times, it would appear that there is considerable scope to improve contour basin systems in the Murray Valley, particularly in the Wakool Irrigation District.

The difference between recommended and actual opportunity times may arise because of differences between irrigator’s and designer’s design criteria. Irrigators generally selected a new basin design based on their enterprise mix and key factors were initial cost, labour requirement and convenience. Bay size is thus determined by the desire for a 12 hour change over. This is at odds with best practice hydraulic design recommended by designers and counter to all agronomic advice. Labour and time constraints make it unlikely that any recommendation to reduce opportunity times will be adopted by irrigators. Automation offers a possible solution.

The paddocks that irrigators choose to upgrade are generally those they consider will produce the greatest net benefit to the farm business. The less developed areas are often more marginal, more difficult to landform or more difficult to supply and are only opportunistically irrigated. Economic data is required to guide decision making and to provide information on the benefits and costs of upgrading contour basin systems.

Economic data is also required to guide the selection of the most appropriate basin design. The non-adoption of level furrow systems in the Murray Valley is attributed to the extensive nature of farms, lower volumes of water per ha and lower reliability of irrigation water compared to Murrumbidgee. Alternatives to raised are beds needed. “Drive-over banks” make controlled trafficking possible in contour basin systems and the extent to which controlled traffic, min-till and stubble retention can generate benefits that justify their adoption over raised bed systems needs to be explored in the Murray Valley. Work is needed to test the efficacy of this strategy in the field and to assess the potential benefits to non-rice crops from improvements in surface soil structure.

Irrigation designers interviewed for this report expressed a preference for a simple design model that could be used to determine optimum bay dimensions (width and length) given supply flow rate, soil type and roughness and based on an opportunity time that suited the most waterlogging sensitive crop. This should follow the
development of a simulation model so that the optimum choice can be determined first and then built into the design model. Given the experiences with CoBaSim, it is also strongly recommended that the model chosen for development be commercially available software that will be supported. SRFR appears to be the better choice.

- There are tools available for evaluating the in-field performance of basin systems. Ultrasonic flow meters are recommended for measuring flows and capacitance depth loggers for measuring advance, recession and surface storage. However, the flow meters need calibration and the minimum number of depth loggers required for the simulation model is unknown. It is recommended that ways of “standardising” inlet/outlet structures be examined to derive a simple, reliable and accurate method of measuring flows with the ultrasonic meters. The minimum number of depth loggers required will need to be determined in concert with the development and refinement of the simulation model.

Areas of further work

1. Collect data from a range of crops (other than rice) to support recommended maximum opportunity times for duplex, heavy clay and sodic soils. This should include field data that (1) characterises the timing and duration of waterlogging on these soil types and (2) tracks soil redox potentials of naturally waterlogged crops.

2. Develop a simulation model that will allow soil infiltration characteristics and roughness coefficients to be determined using inverse modelling of field data from both contour and level basin systems. Technical support for the model needs to be assured beyond the life of this project.

3. In concert with the development of a simulation model, develop standardised tools and evaluate the performance of the full range of common basin systems. The effect of the following design variables also needs to be evaluated: side ditch delivery; terracing; higher flow rates; larger toe furrows; spinner cuts in basins; and sowing with the slope instead of across it.

4. Collect economic data that will allow irrigators to make a more informed choice and assist them in selecting the best basin design for their farm enterprise.

5. This scoping study has also identified a need for automation in basin systems and irrigators interviewed requested information on the performance of outlet structures. This is outside the scope of this project, but they are considered important and there is merit in a separate project examining both these issues with an aim to find the “best” structure and automate it.
1. Introduction

1.1. Background to the study

Rice is seen by most irrigators with General Security access licences in the irrigation districts of southern NSW as their most profitable and reliable crop and, as a consequence, 50-60% of all water delivered to these districts is used to grow rice. It is grown in ponded water to optimise growth and to minimise the risk of cold temperature induced sterility, so production is only suited to basin irrigation systems. These systems constitute roughly 50% of all the land area laid out to irrigation in southern NSW and, to minimise deep percolation and ensure good water depth control, these systems are located on relatively impermeable, often sodic, heavy clay soils in (very) flat terrain.

Individual rice businesses are generally growing and viable, but the dollar return per megalitre (ML) is relatively low for the most limiting resource: i.e. water (Cummins & Thompson 2002). Despite the low return per ML, these basin systems are profitable because of their very low labour and capital requirements (Rendell McGuckian 1998). However, the low return per ML places a heavy reliance on businesses to maintain scale (ML/family) and the high per hectare (ha) water use makes production sensitive to water price and availability (Denimein LWMP Working Group 1995).

The general decline in the terms of trade for agricultural commodities and the increasing cost and decreasing availability and reliability of irrigation water is affecting irrigated farm profitability in these districts and indications are that these pressures will increase rather than decrease. Rice farmers have maintained their profitability in the past by increasing the scale of their enterprises and buying in more water and this used to be relatively easy to achieve. However, the pressures facing irrigators make it increasingly difficult for them to maintain their profitability in this way.

Switching out of contour irrigation into row-cropping or more intensive industries is difficult and expensive and switching to border check systems offers little prospect for maintaining farm profitability (Rendell McGuckian 1998). There is also little incentive to switch from annual crop systems to more capital intensive industries (e.g. horticulture and dairying) because of the uncertainty and risk associated with the low reliability of irrigation supply for farmers with General Security licences in southern NSW (Frost et al. 2003). There is thus a need to find ways to increase the profitability of rice based farming systems which retain the advantages of basin systems but which return more per ML, are better adapted to a lower and more variable irrigation supply, and do not require a large capital investment.

One way to achieve this is for irrigators to allocate available water to winter crops in years when water is limiting, rather than using it to grow rice. This strategy derives from production economic theory which states that profits are maximised when net returns to the most limiting resource are maximised. Beecher et al. (1995) showed that gross margin returns to land, labour and capital are higher for rice than for viable alternative crops, so the most profitable strategy when water is plentiful is to use the available
water to grow rice. When water is limiting, the most profitable strategy is to spread the available irrigation water equally over a larger area and maximise the average net return per ML (Yaron & Bresler 1983). In Mediterranean climates, this is achieved most effectively by using the available irrigation allocation to supplement winter rainfall and deficit irrigate winter crops (Stewart & Musick 1982; North 2005a).

Rice growers in southern NSW are reluctant to adopt this strategy because of the risks associated with waterlogging in winter and after spring irrigation or from “scalding” when irrigation at flowering coincides with hot weather (North 2004b; North 2005b). Thus, for this strategy to be successful, watering and drainage times in basin layouts need to be reduced so higher yields of winter crops can be achieved with lower risk. Furthermore, this needs to be done in a way that improves the net returns to land, labour and capital from winter crops. If this can be done, then the shift to a more flexible cropping system will provide a viable alternative to predominantly rice based systems.

1.2. Study objectives

The overall objective of this project is to improve the design and performance of basin irrigation systems in the rice growing areas of southern NSW so that they can be used to achieve higher yields for a wider range of crops than is currently possible and to do so with reduced operating and environmental costs. This report details the findings of an initial scoping study conducted as a first step towards achieving this goal. The scoping study had the specific objective to determine the current state of knowledge, practice and tools used for designing basin systems and evaluating their performance.
2. Methodology

Information for this scoping study was collected from reviews of the literature and from semi-structured interviews. There were four main components:

1. A review of current district practices to ascertain the range of variation in basin irrigation design and performance (hydraulic and agronomic).
2. Interviews with individual irrigation designers to determine current best practice and identify “needs” in terms of design information.
3. Review existing basin irrigation design models and software to identify strengths and weaknesses of each and the gaps in knowledge.

Relevant literature was obtained from local sources and from a search of the CAB and Streamline databases.

2.1. Interviews with district farmers

A focus group meeting was held with key farmers, earth moving contractors and irrigation designers. Participants were asked to describe their current practices with respect to their use, design and construction of basin systems and to give an example of something which worked well and something that they would not do again. The focus group were asked to comment on recommended methods for extending the results of the project and specific issues that should be examined in the project.

In addition to the focus group, 35 farmers in eight groups of between 4 to 7 people were interviewed during regular rice industry discussion groups held by John Smith, NSW DPI's district agronomist for the Barham/Moulamein district. The meetings were held at the group leader's house and took 2-3 hours. The discussions were facilitated and semi-structured, with all participants asked the following set of core questions:

1. Describe the type of basin irrigation layouts that you have on your farm.
2. What proportion of the total area you have laid out to basin irrigation has been laser graded; what proportion has been “squared up”?
3. What supply flow rates do you typically use?
4. How long does it typically take to water your basin layouts?
5. What is your average and “best” wheat yield in these layouts?
6. What key factors do you considered when designing a new layout?
7. From your experience with basin irrigation systems, what have you found that works well and what would you do differently?
2.2. **Interviews with designers**

Two designers were interviewed: Michael McBurnie (Deniliquin) and Phil Price (Kerang). Interviews were conducted at the designer’s place of work and took 1-2 hours. They were recorded and notes were taken by the interviewer. To ensure consistency, the following core questions were asked:

1. What information do you need to aid the design process?
2. What models/software do you use and how have they performed?
3. What general indicators of good basin design do you use?

Russell Healy (Moama) and David Laughlin (Barham) were not interviewed but provided comments on a draft of this document.

2.3. **Review of models and tools for evaluating basin system performance**

Malcolm Gillies, Rod Smith and Steve Raines, National Centre for Engineering in Agriculture, Toowoomba, conducted this part of the scoping study. Their review and findings are reported in Attachment 1 to this report “Research needs for the evaluation of basin and bankless systems”.

Their key findings regarding simulation models are discussed in light of the feedback from the irrigation designer’s regarding the software and models that they have used in their practices (Section 7.2, page 39).

Their findings regarding tools for field evaluation of basin performance are expanded upon in the review in Section 8 (page 41).
3. Review of the literature

3.1. Why select basin irrigation systems?

World-wide, basin irrigation has been selected as the most appropriate irrigation method for rice fields. Moridis & Alagcan (1989) note that the decision to use basin systems is generally based on the following considerations:

- it suits very flat topography
- maintenance requirements are low (compared to furrow/bed irrigation).
- operation of the system is easy and can be managed by a single person
- labour and energy requirements are minimal so operating costs are very low
- the simple construction is less expensive than alternatives and may increase profitability given that socio-economic research has shown that the availability of capital is the most important constraint to agricultural production.

As well as this, distribution uniformity and overall application efficiency in properly designed level basin systems can be high (> 90%) on low to medium intake soils. Contour basin systems only achieve this same level of efficiency on very low intake soils. The lack of tailwater runoff and the ease with which saline, sodic and toxic ions can be leached are also advantages of basin systems. (U.S. NRCS 1997)

On the Riverine Plain of southern NSW, reconnaissance soil surveys in the 1940’s identified large areas of heavy clay soils that were often sodic (Smith 1945; Smith et al. 1943). These “far levee” soils, principally the non-self-mulching clays and sodic transitional red-brown earths (Hughes 1999), occupy the lower part of the Riverine landscape and their low slope and low permeability are the main reasons for the development of basin irrigation in southern NSW as opposed to other irrigation methods (Water Resources Commission 1976). Other reasons for the selection of basin systems for growing rice in the irrigation districts of southern NSW are:

- the high yields, low production risk, industry support and the high returns per ha, per unit of labour and per unit of capital from rice (McGowan International Pty Ltd 1986; Beecher et al. 1995)
- relatively low capital cost which suits the reliability of supply associated with general security irrigation water licences (Frost et al. 2003);
- low labour input compared to other systems (Rendell McGuckian 1998);
- compatibility with a gravity fed channel system supplying a low, continuous flow during summer which avoids the autumn and spring watering peaks for winter crops and pasture (Water Resources Commission 1976).

Level basins have particular advantages (Erie & Dedrick 1979; U.S. NRCS 1997):

- they are the easiest to manage of any irrigation system and can be easily adapted to automation
- they are suited to furrow as well as flatbed field crops as, unlike sloping surface systems, an even advance across the width of the bay is not critical
• high flow rates can be used to decrease irrigation time and increase application efficiencies. This allows basins to be large (4-16 ha), reducing the number of structures needed and allowing them to be worked with large machinery (with attendant labour and machinery efficiency gains).

The principal differentiating advantage given for contour basins, on the other hand, is their low installation cost.

3.2. Limitations of basin systems in the southern NSW

3.2.1. The disadvantages of basin systems

The limitations of basin systems include (Erie & Dedrick 1979; U.S. NRCS 1997):

• Excess water on impermeable soils can lead to waterlogging, deep drainage and evaporation losses and, in hot climates, scalding of crops
• Laser grading is essential to achieve uniform water distribution
• Soil variability within basins can result in poor distribution uniformity
• Large flows are needed to achieve high distribution uniformity and application efficiencies, necessitating large, costly structures and erosion control measures.
• Larger application depths are needed than for graded borders because a higher head is needed to cover contour basins or drive water to the end of level basins.

For level basins, the amount of land levelled is limited by the depth of topsoil and earthwork volumes may be greater than for other surface irrigation methods so the cost of land-forming can be high.

Rendell McGuckian (1998) outlined the major disadvantages of contour basin systems for growing rice in southern NSW. These were:

• Low returns per ML
• The system is dominated by rice so it is sensitive to changes in rice price
• No other ponded enterprise (apart from rice) is viable in the long term
• Switching from contour systems to other systems is difficult because of soil type and slope restrictions and because the income required to repay capital investment may not be sufficient when changes are required to be made
• They are slow draining, so waterlogging is the major impediment to productivity

3.2.2. The impact of waterlogging

Waterlogging has been recognised as the major constraint to irrigated productivity in the southern Riverina since the inception of the irrigation schemes (Smith et al. 1943; Brewer 1945; NSW Department of Agriculture 1966) and its impact on irrigated productivity has been widely studied (Mason et al. 1984; Meyer et al. 1985; Meyer & Barrs 1988; Humphreys et al. 1991; Melhuish et al. 1991; North 2004b; North 2005b). Grieve et al. (1986) examined the nature and extent of waterlogging in the Murray Valley and estimated that losses due to waterlogging exceeded 12% of the value of the District’s agricultural production. Given that the total value of farm gate product is
currently about $650 million in a full allocation year (ABARE 1998; Frost et al. 2003), then this equates to roughly $80 million in today’s terms.

In the Berriquin Irrigation District, soil types with poor drainage occupy about 150,000 ha (45% of the District). The problem areas are located mainly in the north and the west of the District and the major soil group is the red-brown earths (Grieve et al. 1986). In the Wakool District, Grieve et al. (1986) estimated that 50% of the red-brown earths and 80% of the grey and brown clay soils are poorly drained and thus 24,800 ha (73%) of the total Irrigation District has soils predisposed to waterlogging. Areas with reasonable slope (> 1:750) are confined to the near levee soils (which are also lighter in texture and have reasonable internal drainage).

Fine textured soils, sodicity at depth, low saturated hydraulic conductivity and flat to very flat slopes (< 1:1500) provide conditions suited to the production of paddy rice. These conditions are the antithesis of those required for the production of intermittently irrigated upland crops (Loveday 1985; McGowan International Pty Ltd 1986; Beecher et al. 1995) but they can also result in considerable losses in the rice phase of the rotation. Wet conditions in spring can delay rice sowing and waterlogging in autumn can result in downgrading of rice quality, increased harvesting and transport costs and increased land reformation and preparation costs. Using 1995 prices, Hallows et al. (1995) estimated total average annual losses were $43/ha/year with an inundation of less than one day and this rose to $75/ha/year with an inundation period of 30 days. Losses can be higher (> 500$/ha) for individual rice crops if sowing is delayed by spring waterlogging and the crop encounters cold night temperatures during early pollen microspore (J. Fowler, pers. comm.). Reducing the incidence of waterlogging in basin systems should improve productivity in all phases of the rice rotation.

3.2.3. The causes of waterlogging

Waterlogging occurs when irrigation and rainfall exceed evaporation and soil water storage. In the southern Riverina, it is primarily a problem during winter and early spring and is a consequence of extremely low hydraulic conductivity in many soil types and the very flat nature of the terrain. Reported hydraulic conductivities range from 0.02-0.5 to 1 mm/day for the sub-soils of transitional red-brown earths and uniform, swelling clays respectively (Bridge & Kleinig 1968; van der Lelij & Talsma 1978). The low infiltration occurs because a ‘throttle’ develops in the top of the B horizon of the soil following wetting (Bridge and Collis-George 1973; Loveday et al. 1978). This ‘throttle’ is removed when the soil dries and cracks, but reforms again upon wetting. This occurs in the red-brown earths and in the grey and brown soils of heavy texture, both of which are the predominant soil types used for growing rice (Hughes 1999).

High soil sodicity (i.e. ESP > 6) is common in Riverina soils (Smith 1945; Smith et al. 1943) and is a major factor contributing to their low hydraulic conductivity and their predisposition to become waterlogged (Bridge & Kleinig 1968; Bridge & Tunny 1982). In a sodic soil, O₂ flux at 15 cm depth has been shown to fall by more than 90% and then remain at less than 25% of initial values for a further 12 days following a 12 hour irrigation event. Recovery to initial (pre-irrigation) values was predicted to take another
28 days (Sharma & Swarup 1988). Even in non-sodic soils it can take 7-10 days for redox potentials to reach aerobic conditions following drainage and the removal of waterlogged conditions (Setter & Waters 2003).

3.3. Improving productivity in rice farming systems

Loveday (1985) suggested four strategies for improving the irrigated productivity of areas of flat slopes, high clay content and high sodicity: dedicating areas for permanent rice growing; improving drainage; applying gypsum; and improving soil management.

3.3.1. Permanent rice growing areas

This has also been recommended by Marston & Lacy (1986) and Beecher et al. (1995) and adopted by some farmers (I. Mason, pers comm.). Its principal advantage is that irrigation systems are built to suit soil characteristics and crops are selected to suit the irrigation system. However, it ties up capital in layouts that may only be suited to growing a limited range of crops and this lack of flexibility is its principle disadvantage.

70-80% of the Wakool and Denimein Districts is classified as poorly drained (Land & Water Conservation, pers. comm.). Adoption of this strategy in these districts would result in a heavy reliance on one commodity (i.e. rice), leaving farmers vulnerable to changes in the price of rice (Rendell McGuckian 1998) and water (MDBC 2004). Stronger rotations and greater cropping diversity in farming systems are significantly less risky than monoculture practices and result in higher yields and reduced costs (Helmers et al. 2001). Consequently, this strategy may only be successful in the long term for farms containing enough area of rice and non-rice soils to ensure diversity.

3.3.2. Better irrigation application systems with improved drainage

Beecher et al. (2005) reviewed the use of permanent raised beds in the irrigated farming systems of southern NSW. They chart the evolution of these systems, from the pioneering work by Martin Maynard at Hay in the 1970’s (Maynard & Muir 1984; Maynard et al. 1991), the development of the Tatura bed system for irrigated double cropping in the 1980’s (Adem & Tisdall 1984; Adem & Tisdall 1986; Tisdall & Adem 1987; Tisdall & Adem 1988) and the development through the 1990’s of raised beds in terraced, bankless channel irrigation layouts suitable for use in rice-based farming systems (Thompson & North 1994; Beecher et al. 1994; Thompson et al. 2003).

Beecher et al. (2005) describe the following benefits of permanent raised bed systems:

- Yield improvements
- Improved timeliness of operations and greater opportunity to double crop
- Adoption of precision farming with attendant cost savings
- Greater cropping flexibility allowing selection of the most profitable crop
- Decreased soil compaction within the crop area
- Less draft power is required, allowing smaller tractors to be used
- Increased opportunity to use residual moisture
Significant labour savings are also possible when raised beds are incorporated into terraced, bankless channel, basin irrigation systems for summer row-cropping. These savings accrue because syphons are no longer needed for furrow irrigating and this has been the main reason for the recent rapid adoption of this system in the Murrumbidgee Valley (Michael Grabham, pers. comm.).

Beecher et al. (2005) estimated that up to 35,000 ha in the Murrumbidgee valley is laid out to irrigated raised beds, but only 5,000 ha in the Murray Valley. They attributed the limited adoption of raised beds in the Murray Valley to the perceived high capital cost of landforming, irrigation infrastructure and machinery; the lack of any appreciable yield increase in dry years (see Thompson 1999); lower reliability and availability of water in the Murray Valley and infrastructure impediments such as low flow rates which make the high capital cost of permanent raised bed infrastructure difficult to justify; a lack of promotion; and poor access to markets for ‘alternative’ crops.

Irrigation intensity is considerably lower in the Murray Valley, with 50% of the district laid out for irrigation and only 50% of this area irrigated in any one (full allocation) year (Evans 2004). Most farms, therefore, have a mix of irrigated and unirrigated crops in irrigation layouts as well as crops in dryland areas. Investing in two sets of machinery (one to suit dryland/broadacre cropping and the other for bed farming) is beyond the financial resources of most farms. Furthermore, livestock are an important component of most irrigated farm businesses in the Murray Valley and management of stock is difficult in paddocks with permanent beds (sheep get cast in furrows and checking stock and mustering on a motorbike is slower and less convenient).

Clemmens (2000a) reported that watering and drainage times were decreased in level basins when spin ditches (200 mm wide by 75 mm deep spoon drains) were constructed every 30-60 m in both principle directions of the field. A preliminary trial at Deniliquin indicates that these do work in contour basins and they may be better suited to mixed farming enterprises in the Murray Valley than raised beds. Further work is needed.

### 3.3.3. Application of gypsum

The use of gypsum for improving the water holding capacity, infiltration, hydraulic conductivity and stability of sodic soils in the Riverina is well documented (Bridge & Kleinig 1968; Loveday et al. 1970; Bridge & Tunny 1982; Rengasamy et al. 1984; Rengasamy & Olsson 1991; Rengasamy & Olsson 1995). For the rice growing areas of the western Murray Valley, gypsum is considered the only economic way of improving the structure of sodic soils for upland crops such as wheat (Beale 1998) and it is commonly applied at rates up to 2.5 t/ha in the non-rice phase to aid winter crop and pasture establishment (Beale & Humphreys 1995). However, research has shown that gypsum increases deep drainage under rice when applied prior to sowing at rates above 1.25 t/ha (Slavich, et al. 1993; Humphreys & Barrs 1998) and it's use at this
time to reduce muddy water is only recommended as a last resort for highly dispersive soils (ESP >10%) and at rates less than 2 t/ha (Beale 1998).

Humphreys & Barrs (1998) examined the use of high molecular weight polyacrylamides (PAM’s) for controlling muddy water and found they were effective when tested in the laboratory but failed in the field. They attributed this failure to the lack of high valency cationic sources in the irrigation water. Sivapalan (2005) tested this in the laboratory and found that PAM controlled muddy water without affecting infiltration or percolation in two sodic rice soils from Wakool when applied at a rate of 5-10 kg/ha combined with gypsum at a rate of 25 kg/ha. Further studies are needed to test the efficacy of this strategy in the field and to assess the potential benefits to following non-rice crops from any improvements in surface soil structure.

3.3.4. Improved soil management

Management practices that improve the physical fertility and water productivity of irrigated soils such as those found in the Murray Valley have been well studied (e.g. Rengasamy et al. 1984; Charman 1985; Sedaghatpour et al. 1995; Beale & Humphreys 1995; Hatfield et al. 2001; Stapper 2004). In summary, reducing cultivations and retaining stubbles will increase organic matter. In red-brown earth and transitional red-brown earth soils, this will reduce slaking and the severity of crusting and hardsetting. It will also improve soil structure, providing better anchorage for plant roots and reducing the incidence of lodging. In sodic soils, a reduction in mechanical disturbance caused by cultivation and an increase in organic matter will reduce dispersion and improve infiltration and water conductivity. In all soils, retained stubbles will decrease bare soil evaporation (leaving more water for the crop) and reduce raindrop impact and crusting (increasing infiltration). Removing stock from wet cropping paddocks, reducing cultivations and controlling traffic will eliminate compaction, allowing deeper root growth and increasing the amount of plant available water as well as decreasing the risk of lodging. All of these factors are interlinked.

Landholder surveys in the Murray LWMP areas show that approximately 65% of croppers practice direct drill, yet only 15% of wheat and rice stubbles are retained, with the rest being either baled, burnt or grazed (Evans 2004). The key reason for this apparent discrepancy in practice is the amount of stubble (6-10 t/ha) produced by irrigated crops and the difficulty of sowing following crops into these heavy stubbles.

In addition to the low rate of stubble retention, discussions with growers during the course of this study indicate there is little uptake of controlled traffic in basin irrigation systems in the Murray Valley (apart from areas of permanent raised beds). In contrast, it is estimated that 20-30% of growers with centre pivot or
lateral move irrigators have adopted controlled traffic and precision guidance systems. It is presumed from this that the adoption of controlled traffic in rice farming systems is limited by the size of irrigation bays and the need to do all turning within the bay in conventional systems.

As can be seen from Figure 1, of four primary management objectives, improving soil structure through controlled traffic would seem to be the best example of how the benefits of raised beds might be matched by zero or minimum till systems on the flat (Roth et al. 2005). The extent to which controlled traffic can generate benefits that justify its adoption over raised beds systems needs to be explored in the Murray Valley where extensive systems on the flat predominate.

![Figure 1. The interface between raised bed systems and zero-till on flat fields (Roth et al. 2005).](image)

### 3.4. Improving returns to land, labour and capital

Robotham & Walsh (1995) note a number of benefits of a shift to controlled traffic systems. These include a 0-10% increase in yield; an average reduction in machine draft for tillage of 40% (range 15-55%); and an 8-13% improvement in tractive performance from driving on permanent, compacted wheel tracks. This last effect can lead to an overall reduction in fuel consumption of 30% (Mason et al. 1995).

Chapman et al. (1995) reported that controlled traffic systems improved the timeliness of operations (earlier trafficability after rain, higher groundspeeds and the ability to operate accurately at night), were less fatiguing for operators, eliminated overlaps and reduced tractor costs (e.g. fuel savings at planting were 2.3-8 L/ha). The cost of machinery modifications and harvester-tractor incompatibility were cited as the main problems associated with a shift to controlled traffic. Of particular relevance to this report, the Queensland farmers surveyed who had wide machinery reported that working within (erosion control) contour bays reduced efficiency by as much as 20-30% due to overlaps in irregular-shaped bays. Using parallel banks and eliminating overlaps decreased fuel, seed, chemical and fertiliser input costs.

Mason et al. (1995) compared controlled traffic and zero till systems with conventional practices on a property in the South Burnett region of Queensland. They found that
under the most sustainable system of controlled traffic and zero tillage, labour requirements halved but variable costs increased (principally due to increased herbicide use), yet profitability increased by more than $100/ha or around 30%. Added to this, the total capital tied up in machinery fell by $78,000.

In the Burdekin Irrigation Area, McPhee et al. (1995) found that controlled traffic combined with stubble retention and direct drilling improved the timeliness of field operations when row cropping and improved the probability of successful double cropping. Energy use was reduced by 66-72%, crop emergence and yield were unaffected and there were slight improvements in soil structure over a three year period. Shifting to controlled traffic resulted in a 36% reduction in operating cost and a shift to controlled traffic and direct drill, a 71% reduction (operating costs included repairs, maintenance, fuel and oil but not labour). With respect to permanent raised bed systems, Maynard et al. (1991) compared permanent and conventional bed farming using an actual case study and found that the return to capital for permanent beds was nearly 9% compared to just over 5% for conventional tillage.

The advent of auto-steer and GPS precision guidance has increased the potential economic benefits of controlled traffic systems. A 2 cm auto-steer GPS system reduced inputs by $7/ha on the medium-rainfall sand-plain of WA (Blackwell et al. 2003). This was considerably less than the $37/ha benefit from reduced compaction, but roughly equivalent to the $9/ha saving from reduced fuel consumption ($3/ha) and reduced herbicide usage with shield spraying ($6/ha). Other research in WA has reported benefits of $5-$63/ha from matching input rates to production potential with a precision agriculture system. However, cropping area drives many of the total benefits from new technologies, as only larger programs (> 1500 ha) are able to repay the higher costs of auto-steer whilst smaller programs use marker arms. (Isbister 2006)

If irrigators wish to maximise their returns to total capital, they have to maximise the returns to their most scarce resource. McGowan International Pty Ltd (1986) compared two case study farms: a “typical” rice farm preferentially allocating water to rice (low efficiency) and a high efficiency farm preferentially allocating water to maize with rice grown as a residual crop because of its low returns/ML. With average water availability the returns to capital were 5.2% and 13.9% for the low and high efficiency farms respectively, which reflects the benefits of systems where water can be preferentially allocated to crops with higher returns/ML. Potential returns to capital, however, were predicted to be 28.0% for low efficiency farms, which was 5.8% greater than predicted for high efficiency farms. While these potential values appear high, they do show that the strategy to minimise capital investment and grow low risk crops on rice farms typical of those in the Murray Valley may be economically justified if higher yielding varieties, laser levelling, drainage recycling and better crop management are adopted.

Rendell McGuckian (1998) found that farms relying on basin systems to grow rice were very susceptible to any change in the returns from rice and that switching from contour systems in order to grow other crops was difficult. Their report highlights the over-reliance on one commodity (i.e. rice) in contour basin systems in the southern Murray-Darling Basin. There is a clear implication from this and the McGowan International
(1986) report that more flexible irrigation systems are needed so that the crops returning the most per ML can be selected from a wide range without the capital cost involved in changing layouts. This is confirmed by Singh & Beecher (2005), who found that the limited scope for growing other high-value summer crops in natural contour designs resulted in gross margins that were roughly 50-60% of those achieved from a possible cropping sequence grown on permanent beds in level basins.

3.5. Improving irrigation efficiency in basin systems

The design of an efficient basin system for the irrigation of upland crops in ricelands must meet the following requirements (Moridis & Alagcan 1989):

- minimise deep percolation
- alleviate waterlogging by ensuring infiltrated water does not reach the traffic pan
- high application efficiency (> 85% in practice but ≥ 90% for design purposes).
- high uniformity.

McGowan International (1986) examined irrigation efficiencies\(^1\) of contour systems for growing rice as well as for other crops and pastures in the Murrumbidgee Irrigation Area. In natural contour systems that had not been laser graded, they observed average irrigation efficiencies of 57% and 55% for rice and non-rice crops respectively. If soil types were better, paddocks less fragmented or drainage recycling had been installed, efficiencies increased to 72% and 81% for rice and non-rice crops respectively. In lasergraded, landformed parallel contour systems, efficiencies were further increased to 82% and 88% for rice and non-rice crops and rose to 95% for non-rice crops if drainage re-use was installed. Farm surveys in Mississippi and Arkansas confirm that laser grading and the straightening up of contour levees results in significant water savings (up to 40%) within the rice phase of the rotation (Smith et al. 2007) and an irrigation efficiency of 85% is considered achievable, if not standard, for level basin systems in the USA (Clemmens 2000a).

In keeping with these findings, laser grading, drainage recycling and on-farm storage have become standard practice and key strategies for improving on-farm irrigation efficiencies under the Murray LWMP. The restriction of rice production to low permeability soils (Murray Irrigation Ltd 2004) to minimise deep percolation losses has also improved irrigation efficiency in the rice phase of the rotation (Humphreys et al. 2003). However, low system delivery rates were also identified as a key irrigation efficiency limiting factor by McGowan International Pty Ltd (1986) and this has not been able to be addressed for most irrigators on MIL supply who have access to peak flow rates of only 10-13 ML/day. River pumpers (20 to 40+ ML/day) and irrigators with double wheels (≈ 20 ML/day; D.Hall, pers. comm.) have greater scope for improving irrigation efficiency because they can access high flow rates.

\(^1\) Irrigation (engineering) efficiency (%) = (diversions – losses)/diversions * 100
The ability to generate high flows on-farm allows opportunity times for free water to be reduced, thus reducing deep percolation losses. Malano & Khanna (2001) confirm this, as they found that long opportunity times in a lasered, parallel contour basin with side-ditch delivery did lead to excessive deep percolation. However, they concluded that the main factor causing over-irrigation and excessive deep percolation was slow drainage of free water off the bays. This was attributed to excessive micro-topographical relief (the paddock needed re-lasering), poorly maintained toe-furrows, insufficient outlets (in number and size) and excess water application.

North (2004a) concluded that measures to improve paddock drainage fall into three categories: increasing the slope of the water surface (e.g. deeper, larger and cleaner drains), reducing the length of the flow path to a drain (e.g. straighter banks, raised beds, more drainage outlets) and reducing surface roughness (e.g. laser grading, drill rows down the slope instead of across the slope, direct drill). It is likely that resident times will be reduced by a combination of all of these factors, but the most cost effective combination leading to the greatest reduction in deep percolation is unknown.

McGowan International Pty Ltd (1986) also emphasise the importance of channel and drainage infrastructure for obtaining a high degree of on-farm water control, a position also strongly advocated by irrigation designers (M. McBurnie, pers. comm.). This control is provided by:

- well placed and water-tight control structures
- clean channels and drains (without reverse grades)
- the means of determining flow rates and volumes (i.e. meters)
- correctly sized channels and drains
- avoiding permeable soils
- using high flow rates to minimise opportunity times
- the ability to totally drain channels when not in use

3.6. “Best practice” design recommendations

Khanna et al. (2003a) found there were no standard design and management criteria available for basin layouts in Australia and that overseas criteria and experience were not directly applicable.

3.6.1. International studies and design recommendations

3.6.1.1 US Soil Conservation Service

The U.S. Soil Conservation Service (1969) makes the following recommendations:

- **Crops** - must be able to withstand temporary flooding for 12 hours or more.
- **Soils** - basin systems are only suited to medium to fine textured soils
  - the available water holding capacity should not be less than 0.1 mm/mm nor less than 65 mm for the root zone depth
- **Slope** - the minimum slope to provide adequate drainage is 0.05 to 0.15%
3.6.1.2 US Natural Resources Conservation Service

Irrigation system design criteria and procedures are described in detail in the U.S. Natural Resources Conservation Service (1997) National Engineering Handbook. It is noted that the design of basin size depends on water supply flow rate, soil intake characteristics, available soil water capacity, and flow resistance of the crop/pasture. Design procedures are based on the zero-inertia model and the Surface Irrigation Model, SRFR (Strelkoff, et al. 1998). The following points are of particular note:

- Large flows are desirable and typically need to be in the range 12-17 ML/day to meet the minimum flow depth requirement.
- In general, the entire basin should be covered by water in less than half the total required opportunity time. For highest distribution uniformity, total coverage should take place within a fourth of the required irrigation opportunity time.

3.6.1.3 US Water Conservation Laboratory

A considerable amount of work has been conducted in the USA into level basin systems (e.g. Clemmens & Dedrick 1982; Clemmens et al. 1989; Strelkoff, et al. 1998; Clemmens 2000a; Clemmens et al. 2003; Playan et al. 2004). However, overseas criteria generally apply to single, hydraulically independent closed basins and so are not applicable to contour basin systems in NSW (Khanna et al. 2003a).

3.6.2 Australian and local design recommendations

3.6.2.1 IREC Farmers’ Newsletter

Many articles relating to “good” contour irrigation design have been published in the IREC Farmers’ Newsletter over the past 20 years (e.g. Mann 1990; Mann 1991; Grogan 1991; Swinton & Beale 1990; Grogan & Swinton 1993). The more relevant design recommendations are summarised in this Section and Section 3.6.2.3. It is of note that no recommendations were found regarding the ideal flow rate for a given basin size.

Marston & Lacy (1986) recommended management options for land of various grades in southern NSW (Table 1). They note that no crops (except rice) and no pastures (except Persian clover) are well suited to impermeable heavy clay soils but, if slopes are greater than 1:2000, they can be cropped if beds or hills are used. Rice is considered well suited to uniform natural slopes of 1:1500 to 1:5000, whilst slopes > 1:1500 are suitable (though not optimum) for other grain and pasture crops.
Table 1. Recommended management options for various grades for basin irrigation systems in southern NSW (adapted from Marston & Lacy 1986).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Recommended Management Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flatter than 1:2500</td>
<td>Poor drainage control</td>
</tr>
<tr>
<td>1:2000 to 1:2500</td>
<td>Acceptable for rice but drainage may be a problem</td>
</tr>
<tr>
<td></td>
<td>Acceptable for infrequent watering of annual pasture</td>
</tr>
<tr>
<td>1:1500 to 1:2000</td>
<td>Small bay size required to maintain 5 cm contour</td>
</tr>
<tr>
<td></td>
<td>Acceptable for infrequent watering of annual pasture but not recommended for crops</td>
</tr>
<tr>
<td>1:1000 to 1:1500</td>
<td>Less desirable for rice because 7.5 cm contour used</td>
</tr>
<tr>
<td></td>
<td>Acceptable for irrigation of winter crops and pastures and infrequent watering of lucerne (using border check)</td>
</tr>
<tr>
<td>Steeper than 1:1000</td>
<td>Not recommended for rice</td>
</tr>
</tbody>
</table>

Swinton & Beale (1990) stated that each bay should be able to be watered and drained in 24 hours or less. They showed how this could be achieved by moving away from bay-to-bay supply and drain in "traditional" natural contour basins to supplying each bay directly (from a channel or a side-ditch), improving drainage (by placing the supply below ground level) and landforming and laser grading. Hoogers (1991) recommended irrigators should aim to have water applied within 4 to 8 hours and drained in 6 to 8 hours for non-rice crops and the WheatCheck recommendation is to have water on and off in 15 hours (Varley, et al. 1999).

Hoogers (1991) recommended a flow rate of 2.5 ML/day per 10 m width for border check systems, with a minimum of 1.6 ML/day for heavy soils, whereas Swinton (1992) recommended rates between 1.3 and 1.75 ML/day per 10 m width of bay.

3.6.2.2 Kerang bay hydraulics work

This work commenced in 1980 to develop procedures/models for describing the hydraulics of border check irrigation of dairy pastures (i.e. infiltration function, hydraulic roughness and advance and recession phases) and to develop a suitable design procedure (VIRASC 1985; Campbell 1989). The main conclusions were:

- **Advance** – was substantially affected by both flow on to the border and by pasture height but not significantly by slope. Advance times at flow rates between 3.3 and 9.5 ML/day onto bays 30 × 300 m were between 3 and 6 hours.

- **Recession** – was affected by slope and pasture height. The total recession time for the whole bay (30 × 300 m) was 17 and 26 hours for short and long grass respectively when slope was 1:1000 and 20-40 hours when slope was 1:1500.
• *Residual depth*\(^2\) – was affected by slope. Average depths were 3 mm (range 0-16 mm) on bays with 1:750 slope and 8 mm (0-16 mm) on bays with 1:1500 slope.

It was determined that the major areas requiring work were waterlogging, soil infiltration characteristics and the hydraulics of the recession phase.

### 3.6.2.3 Swinton

Extension material regarding best practice basin irrigation design was developed by Richard Swinton, NSW Agriculture, Deniliquin, in the 1990’s as part of the Salt Action program. The following best practice criteria for contour irrigation systems are a summary of his work (Swinton 1993; 1994; and 2000).

1. **Bay size**
   - The maximum bay size for rice of 4 ha is too large for cereals and pasture unless very high flow rates are available
   - First and last bays should be smaller to speed water cover of the first bay and reduce tail water from the paddock
2. **Flow rate**
   - for rice, bays should be able to be filled in less than 12 hours
   - for pastures and cereals, bays should be able to be filled in 4-6 hours
3. **Infrastructure**
   - infrastructure should be able to handle high flow rates (15 to 20 ML/day)
   - bay outlets should be large: 1 to 1.5 m wide
4. **Slope**
   - slopes of 1:750 to 1:1200 work best
   - waterlogging is inevitable with slopes flatter than 1:2000
   - on flatter areas, contour layouts may provide better drainage than border check because of the shorter distance to a “drain” (i.e. the toe furrow)
5. **Contour interval**
   - < 75 mm for rice. 50 mm is ideal.
6. **Bay length**
   - no longer than 400 m between outlet points (or 450 m with side-ditch layout)
   - banks should be as straight as possible to facilitate drainage
7. **Supply**
   - each bay should have an inlet from the supply
8. **Drainage**
   - each bay should have access to a drain. Drainage from bay to bay through the toe furrow is not recommended.
   - for slopes flatter than 1:2500, bays should be individually drained

\(^2\) Residual depth is defined as the depth of water lying on the bay when dynamic recession has ceased.
- toe furrows should be 15–25 cm deep, free from obstructions and continuous. A slope of 1:2000 is needed to ensure drainage, so if effective depth is 15 cm, then banks should be no longer than 300 m.
- paddock drains are necessary and should be deeper than the toe furrows. The sill of bay outlets should be set near the bottom of the toe-furrow.
- Bay to bay outlets should be located at each end of the contour bank

9. Access
- it should not be necessary to “knock in” banks as this usually impedes drainage
- access points should be on the high side of the bay in conventional layouts

3.6.2.4 Khanna and Malano

Manoj Khanna and Hector Malano (University of Melbourne) examined ways of improving the efficiency and flexibility of contour irrigation in south east Australia (Malano & Khanna 2001; Khanna et al. 2003a; Khanna et al. 2003b; Khanna et al. 2003c). They developed a model for soil infiltration and a two-dimensional simulation model (CoBaSim) for sequential basins (regular and irregularly shaped) that accounted for line inflow through a side-ditch and flow in toe furrows. Following verification using field data, the model was used to develop the following guidelines.

1. Aspect ratio (AR = the ratio of width to length of the basin)
   Increasing the AR from 0.3 to 1.0 significantly increased the advance time with constant inflow per unit width. The authors concluded that if AR is increased, inflow per unit width should be increased more than proportionally in order to maintain advance time. Application efficiency and distribution uniformity decreased when AR increased from 0.3 to 0.5 but were relatively insensitive at values > 0.5.

2. Longitudinal slope
   Mild slope in the advance direction improves performance. The steeper the slope (1:3330 to 1:1250), the more rapid the advance and more uniform the application.

3. Inflow rate
   Higher flows led to higher efficiencies and uniformity but should be used judiciously to avoid excessive application depth. Similarly to one-dimensional flow layouts, advance time was highly sensitive to inflow rate.

4. Elevation difference between basins
   After an initial decrease in advance time, increasing the vertical displacement (in the range 5 to 15 cm) between bays by > 7 cm did not significantly increase drainage outflow, and the flow behaviour in both basins was independent of each other.

5. Local micro-topography
   An increase in local undulations decreased irrigation efficiency and distribution uniformity, confirming the need for laser levelling and showing the importance of regular maintenance (re-grading) to reduce surface irregularities in these systems.

6. Number of drainage outlets
   Using a second drainage outlet between basins had 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.
4. Current district practice

The responses from the discussion groups reported here, whilst similar in many respects (i.e. rice based mixed farms), often differed between groups with regard to attitudes to some practices. This may have been related to supply (some groups had access to higher flow rates) or soil type and slope, but it also appeared to depend on the dynamics within the group, particularly the attitudes and practices of the "leading" farmers.

4.1. Extent of basin irrigation development

Table 2 shows that only 50% of the Murray LWMP area is laid out to irrigation and, when irrigation allocations are 100%, only 50% of this area is irrigated in any one year. Of the area laid out to irrigation, roughly 50% is laid out to contour irrigation and 50% to border-check irrigation. There is a gradation in the region from courser textured, less sodic, red soils and steeper slopes in the east and south to finer textured more sodic, grey clays on flatter country in the north and west. This is reflected in the predominance of contour systems for rice growing in the Denimein and Wakool Irrigation Districts.

Table 2. Developed irrigation area in each of the four Murray LWMP areas and the areas under each of the major types of irrigation application systems (source, Evans 2004).

<table>
<thead>
<tr>
<th></th>
<th>Berriquin</th>
<th>Cadell</th>
<th>Denimein</th>
<th>Wakool</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Area</td>
<td>337,669</td>
<td>298,683</td>
<td>53,347</td>
<td>210,575</td>
<td>900,274</td>
</tr>
<tr>
<td>Developed Area</td>
<td>238,542</td>
<td>90,932</td>
<td>33,382</td>
<td>95,099</td>
<td>457,955</td>
</tr>
<tr>
<td>% of total area</td>
<td>70.6</td>
<td>30.4</td>
<td>62.6</td>
<td>45.2</td>
<td>50.9</td>
</tr>
<tr>
<td>Area in contour</td>
<td>70,655</td>
<td>38,485</td>
<td>23,184</td>
<td>77,595</td>
<td>209,919</td>
</tr>
<tr>
<td>% of developed area</td>
<td>29.6</td>
<td>42.3</td>
<td>69.5</td>
<td>81.6</td>
<td>45.8</td>
</tr>
</tbody>
</table>

Area laid out to contour irrigation not laser graded

<table>
<thead>
<tr>
<th></th>
<th>Berriquin</th>
<th>Cadell</th>
<th>Denimein</th>
<th>Wakool</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>19,493</td>
<td>19,004</td>
<td>14,692</td>
<td>39,334</td>
<td>92,523</td>
</tr>
<tr>
<td>% of contour area</td>
<td>28</td>
<td>49</td>
<td>63</td>
<td>51</td>
<td>44</td>
</tr>
<tr>
<td>Side-ditch</td>
<td>2,365</td>
<td>4,186</td>
<td>0</td>
<td>622</td>
<td>7,173</td>
</tr>
<tr>
<td>% of contour area</td>
<td>3</td>
<td>11</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Area laid out to contour irrigation that is laser graded

<table>
<thead>
<tr>
<th></th>
<th>Berriquin</th>
<th>Cadell</th>
<th>Denimein</th>
<th>Wakool</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>19,671</td>
<td>7,142</td>
<td>5,583</td>
<td>24,813</td>
<td>57,209</td>
</tr>
<tr>
<td>% of contour area</td>
<td>28</td>
<td>19</td>
<td>24</td>
<td>32</td>
<td>27</td>
</tr>
<tr>
<td>Side-ditch</td>
<td>29,126</td>
<td>8,153</td>
<td>2,909</td>
<td>12,826</td>
<td>53,014</td>
</tr>
<tr>
<td>% of contour area</td>
<td>41</td>
<td>21</td>
<td>13</td>
<td>17</td>
<td>25</td>
</tr>
</tbody>
</table>

The lower level of development in the more extensive areas west of Deniliquin is also apparent from the data presented in Table 2, with roughly 50%-60% of the area in
contour systems still not laser graded in the Cadell, Denimein and Wakool LWMP areas. Whilst this figure does not reflect the amount of landforming that has been carried out since 2004, it may also over state the case, as irrigators indicated that this country was generally more marginal (e.g. poorer soil), was more difficult to landform (i.e. broken or steep slopes, fragmented areas) or was more difficult to supply (i.e. distant from the wheel). Consequently, much of the country in natural contours is only opportunistically irrigated at times of high irrigation allocations.

Of the 35 irrigators interviewed, 18 had more than 80% and 6 had between 60 and 75% of their rice country in lasered, parallel contour systems. The remaining 11 irrigators had 100% of their rice lands in natural contour systems. Most of the irrigators with natural contour systems supplied each bay individually from a farm channel at one end and drained bay to bay from the opposite end.

Of the 35 interviewed, 16 had laser graded more than 90% of their rice country. Of the 11 irrigators with 100% of their rice lands in natural contours, 4 had done no laser grading at all and the remainder had lasered between 20% and 60% of their rice country.

The differences between the groups were highlighted by the fact that 10 of the 11 irrigators who had 100% of their rice lands in natural contours were in just 2 of the 8 groups (7/7 of one group and 2/3 of the other).

A number of irrigators had installed side-ditch delivery systems (actual numbers not recorded). Supply and drainage to each bay occurs through the one structure in these systems and there was scepticism from others regarding their ability to speed watering and drainage. General experience was that a second structure, at the opposite end of the bay to the side-ditch, sped watering and drainage. Many considered that enlarging the toe-furrow improved drainage. Some did so on all sides of the bay, others on one side and others had individual supply to each bay and side-ditch drain at the opposite end.

It has been estimated that 90% of all layouts in the Murray Valley are on a single plane (M. McBurnie, pers. comm.). However, 3 of the 35 irrigators reported installing zero-zero grade on bays in terraced systems. One was terracing steeper country but had access to a double wheel and was able to deliver 20 ML/day. Another irrigator was converting to large terraced bays (10 ha) with large toe-furrows (4.5 m wide and 450 mm deep) on all sides and delivering 26 ML/day through a side-ditch. Interestingly, one irrigator reported installing bays with zero-zero slope but had re-graded these back to a slope of 1:2000 because of drainage problems.

No one reported using raised beds.
4.2. Typical supply flow rates and watering times

Maximum supply flow rates for irrigators on MIL channel supply were generally 10 to 13 ML/day (average 8-9 ML/day). At peak demand times this was reported to fall to 7-8 ML/day. Some irrigators in one of the groups had double wheels, and this allowed delivery of 20 ML/day. Another group were predominantly river pumpers and they were able to supply 30-40 ML/day and up to 60 ML/day in one case.

It was generally agreed that water use was 1.5 ML/ha for the first irrigation and 1 ML/ha for subsequent irrigations. Reported watering rates typically ranged from 4 to 6 ha/day with MIL supply of 10 ML/day. One group had predominantly un-lasered natural contour systems and reported watering rates as low as 3.3 ha/day with MIL supply. Some of the reported irrigation times were:

- 10 hrs on & 10 off on steeper country & 15 hours on & 15 off on flat country;
- 24 hrs on at 11 ML/day
- 0.8-1.0 ha/hr for the first irrigation & 2 ha/hr for the second & subsequent irrigations of a 12 ha bay supplied at 15 ML/day;
- < 6 hrs to fill & 6 hrs to drain for 2.4 to 2.8 ha bays supplied at 10-13 ML/day.

4.3. Irrigator’s recommendations

Participant’s individual and collective experiences were captured in their responses to questions regarding what they found worked well and, given hindsight, what they would do differently. Their responses are summarised below.

4.3.1. What works well?

1. “good” soil
   This was equated with high productivity. Most people retained grades close to natural slope and minimised earthmoving to retain soil structure, though attitudes to top-soiling varied between groups. These differences in attitude may arise because the benefits/costs of top-soiling vary with soil type and depth and these may not have been adequately demonstrated for some irrigators.

2. Lasering to uniform slope and squaring-up layouts

3. slope on bays
   Slope should ideally not be flatter than 1:1200, but certainly not less than 1:2000. One participant created slopes of 1:2000 if land was flatter than this and another re-graded layouts initially installed with zero sidefall (i.e. lateral slope) back to a slope of 1:2000.

4. bay size and shape
   3-4 ha with MIL supply from 1 wheel (many were 4-5 ha), squared-up, and with the width a multiple of machinery widths. Big bays were equated to labour and machinery savings.

5. supply
• individual supply to each bay was considered essential on country flatter than 1:1200
• high flow rates through appropriately sized structures were desirable
• side-ditch delivery in cracking soils, mainly because leaks occur into the paddock, saving labour/time and water
• centre-ditch in natural contour layouts

6. drainage
• individual drainage outlets in each bay to the farm drain and the recycle system
• larger toe furrows improve drainage
• side-ditch drains work well if bays are individually supplied from the opposite end.

7. structures
• concrete and large is best
• stops are best for supply
• pipes are best for drains as they improve access around the paddock

8. other
• using an irrigation designer because it is cost and time effective and because irrigators are able to do a number of designs on paper, get costings on the alternative designs and then pick the best
• basin vs border check
  o border check was considered best for pasture, channel maintenance, lambing and paddock access to check stock
  o assess paddocks on soil type, slope and potential productivity and balance layouts for rice and other crops/pasture. The “best” paddocks are laid out to lasered contour for rice and the rest are laid out to border check to obtain the best possible productivity from winter crops and pastures.

• automation

4.3.2. What does not work?

1. waterlogging
Heavy clay soil, sodicity, cultivation and irrigation/rain cause slaking and dispersion and this leads to low porosity and low permeability of topsoil. Most participants recognised that grey sodic soils were the least productive.

2. excessive earth moving
Poor land-forming practices (i.e. heavy cuts, mixing poor sub-soil into fill areas, not topsoiling) result in lost production for over 20+ years in areas where sub-soils are exposed.

3. flat grades
Zero-zero grades were generally considered good for rice but not for winter crop production in wet years (or a wet rice harvest)
4. **big bays**
These are slow to water and drain and they waterlog easily. One participant felt that to avoid these problems, then the maximum bay size should be 1.6 ha.

5. **side-ditch delivery**
A number of participants felt these did not work on “flat” country. There was no consensus as to the slope below which they failed to be effective.
5. Common basin systems

Contour basin systems typical of those in southern NSW in the early 1990’s are described by Swinton & Beale (1990). The following section describes the range of basin systems observed in the Murray and Murrumbidgee Valleys during this study.

5.1. Contour basins – no trafficking between bays

5.1.1. Natural contour basins

These are often partially or totally laser graded between the banks and, in many instances, banks are made parallel and spaced to suit machinery widths to reduce overlap and increase operational (machinery) efficiency. Interviews with farmers in Barham/Moulamein district showed all growers who had this system individually supplied each bay and drained bay-to-bay from the opposite end of the bay to the supply. This is an improvement over “traditional” designs which water bay-to-bay.

![Figure 2. Representation of a “Traditional” natural contour basin system.](image)

**Advantages**
- low capital input (i.e. “economical”)
- suits “broken” country with irregular slopes, tree lots or areas of non-rice suitable soils

**Disadvantages**
- large number of structures
- slow watering and drainage times = inefficient use of water and labour
- poor drainage = high waterlogging risk
- access to the bays can be difficult
• all turning is done within the bays and there is considerable overlapping and machinery inefficiency

5.1.2. Lasered, parallel contour basins

The paddock is landformed and graded to the plane of best fit. Longitudinal check banks are made parallel, though bays are not necessarily squared up. Bays can be supplied individually from the farm channel and drainage is bay to bay. Bay size is generally 3-5 ha.

![Figure 3. Representation of a lasered, parallel contour basin system.](image)

**Advantages**

• Removal of reverse grades with laser grading and shorter check banks = quicker watering and draining than natural contour
• Easier water management
• Machinery efficiency improved

**Disadvantages**

• large number of structures
• watering and drainage times still too long = inefficient use of water and labour
• bay to bay drainage (i.e. high waterlogging risk) unless supply set below ground level to allow drainage back into channel
• all turning is done in the bay

5.1.3. Side-ditch delivery, lasered, parallel contour basin

The side-ditch is a channel cut down one side of the block. This channel is commonly 2.0 to 2.5 m wide, the bed of the channel is 30-60 cm below the level of the bay and there is no bank on the inside of the bay. Check structures (1.0 to 1.2 m wide) are
placed across the side-ditch at each contour bank to control flows and supply and drainage occur though the same structures. Side-ditches can be incorporated into many non-landformed paddocks.

Figure 4. Representation of a side-ditch delivery, lasered, parallel contour basin system.

**Advantages**
- the supply automatically becomes a drain = labour and maintenance saving
- fewer structures (one check structure per bay) = lower initial cost
- good in cracking soils as all leaks occur into the bay, saving water and labour
- permanent access opposite supply = improved drainage, reduced maintenance
- minimal tail-water if drainage from the second last bay is used to water the last (smaller) bay
- winter rainfall drainage is improved compared to traditional toe furrows

**Disadvantage**
- irrigation drainage is restricted on flat grades (< 1:2000) as water “backs up”
- the side-ditch cannot act as a channel for irrigating other paddocks and a separate channel is still needed
- there is only one drainage outlet in each bay and this can restrict drainage
- all turning is done in the bay

**5.1.4. Lasered, parallel contour basins; individual supply and drain**

This system is the preferred design of one local irrigation designer for layouts that are predominantly used to grow rice and sub-clover based annual pastures (M. McBurnie, pers. comm.). Each bay is supplied from a channel and drained into a farm drain connected to a recycle system. The minimum fall from the bay to the bed of the drain is
30 cm. The supply channel is built on a pad and access to each bay is from a roadway constructed on the channel bank. There is a pipe inlet structure to each bay.

![Figure 5. Representation of lasered, parallel contour basins with individual supply and drain.](image)

**Advantages**
- quicker watering
- offers greater flexibility for mid-season drain in rice
- greatly improved drainage
- permanent structures = reduced labour requirement and lower maintenance
- good access to each bay

**Disadvantages**
- drainage water losses – this depends on the distance to the recycle pump
- cost of pumping drainage water
- cost of infrastructure and structures may be an impediment to some
- access can be very difficult if a roadway is not installed

### 5.2. Contour basins with drive-over banks

This evolution in the design of contour basins arose because the Morona family, “East Rostella”, Deniliquin, wanted to develop a system that had greater versatility than current designs, was quicker to water and drain and which had better access into and within paddocks. They developed check banks along the contour that are wide and have low slope so that they can be driven over. This allows paddock to be trafficked up
and down the slope and across check banks, rather than across the slope and within banks as in conventional layouts. Bays have no longitudinal slope.

5.2.1. Morona’s drive-over banks

The paddock has been graded to 1:2000 slope and has a channel supply running down one side and a side-ditch down the other. Check banks along the contour are constructed 6 m wide and 25 cm high and rounded to make driving over them easier for the air-seeder. A 5 m wide shallow drain, instead of a conventional V-shaped toe furrow, is constructed 1 m out from each bank on the low side of each bay. The bed of this drain has a 1:10,000 slope running back to the side-ditch and crop in the bed of the drain is sprayed out to speed up drainage.

![Figure 6. Representation of Morona’s drive-over bank basin system.](image)

**Advantages**

- 6% more crop area because banks can be cropped (Morona 2005)
- lower chemical use as banks are cropped and are no longer sources of weed seed
- increased labour and machinery efficiency – less turning, no headlands
• eliminates the need for cross-overs which concentrate traffic and cause compaction and restrict paddock drainage if not properly installed or maintained.
• better drainage by sowing with the slope (Mannings $n = 0.25$ for small grains with drill rows across the direction of water flow and 0.10 when the drill rows are parallel to the direction of water flow: Moridis & Alagcan 1989)
• better drainage with 80-100 m wide contour basins than if paddock converted to border check with 400 m long bays
• long runs makes is possible to adopt control traffic and precision farming systems and reduce costs and increase farm efficiency.

**Disadvantages**
• it is hard to maintain constant sowing depth with the air seeder over drains/banks
• drive-over banks need to be heightened prior to growing rice
• a road grader is needed to pull down and put up banks if soil is only pulled one way
• have to traffic through wet drains if sowing shortly after a pre-irrigation.

### 5.2.2. Kooloos’ “V-Bay”

This iteration of Morona’s design has been developed by Harry Kooloos, “Amarran” Mayrung. Paddocks originally landformed on a single plane (slope 1:2000) are re-graded within each bay to a double slope of 1:1500 which drains to the centre. This centre drain is 5 cm deep and one scraper blade in width. Bays have no longitudinal slope. The paddock has a side-ditch along both ends of the bays, one with channel stops for supply/drainage and the other with 300 mm pipes to speed drainage. Check banks are constructed so that they can be driven over, allowing the paddock to be trafficked with the slope.
Advantages

- all the advantages of Morona's system
- the check banks are on the high side of each bay so they don’t need to be as high, making them easier to drive over, less likely to crack through and leak and amenable to being pulled down and put up with non-specialised machinery (e.g. a crowder).
- trafficability down the paddock is also improved by placing drains down the centre of the bay and at some distance from the check banks
- the double slope means only half the volume of water needs to be ponded over the bay to achieved complete coverage, resulting in quicker watering and drainage times and reducing the likelihood of water backing up in drains. (This creates the option to increase the bay size and reduce the number of structures).

Disadvantages

- for a paddock already landformed to a single plane, the cost of installing this system is roughly twice the cost of a “touch-up” laser grading
- have to traffic through wet drains if sowing shortly after a pre-irrigation
- a spinner cut along the centre of each drain may be needed to speed winter drainage, or crop in it could be sprayed out

Figure 7. Representation of Kooloo’s "V-bay" basin system.
5.3. Drain-back level basins

Level basin systems have been in use in the United States for nearly 30 years (Erie & Dedrick 1979). In the mid-1980’s, a new form of level basin was developed in which water is drained off after the completion of advance. This system is described by Clemmens (2000b) as a series of benched (i.e. terraced) level basins with the supply channel constructed below grade so that it can provide both irrigation and surface drainage (i.e. bankless channel or side-ditch). The bottom of the channel is typically 30-40 cm below field grade. At each bench, the channel has a check. When closed, the field is irrigated and when opened, the field is drained into the next, lower lying basin. With level furrow systems, Clemmens (2000b) states that application depths of 40 mm can be accomplished with reasonable uniformity.

The number of these systems being installed in southern NSW has increased rapidly in recent years, particularly in the Murrumbidgee Valley. In general, high flow rates are used to speed advance and improve uniformity, so the system is more suited to river pumpers or those with on-farm storage who can supplement scheme supply flows. Clemmens (2000b) recommended flow rates of 350 to 500 L/s (30-43 ML/day), though flow rates of 20-30 ML/day are more commonly used in the Murrumbidgee Valley (M. Grabham, pers. comm.). Clemmens (2000b) also notes that to properly drain one basin into the next lower-lying one requires a 30 cm step between basins. In the Murrumbidgee Valley, growers who have installed these systems have found that a step of 7.5 cm is not enough and they recommend a minimum step of 15 cm. To attain this step bays are generally 130-160 m wide, but irrigators with raised beds and sufficiently high flow rates are happy to go out to 250 m (R. Commins, pers. comm.).

5.3.1. Level basins

These terraced, level basins are designed principally for rice growing in rotation with winter crops and pastures. Water is delivered to the bays through a side-ditch on one side of the paddock and then moves around each bay in large toe-furrows (2-4 m wide by 30-60 cm deep) around the outside before spilling over and covering the basin. High flows rates are used to reduce opportunity times and improve irrigation efficiency.
Advantages
- lower development cost over more conventional basins
- less head of water needed to cover bay = shorter opportunity time
- good water depth control for rice
- ease of automation
- labour savings

Disadvantages
- potentially poor winter drainage
- poor access into bays and between bays
- limited ability to move to more efficient machinery practices

5.3.2. Level furrows

These systems have been developed by cropping enterprises, primarily as a way of reducing the irrigation labour requirement in row cropping (i.e. eliminating the need for siphons), but also to allow a wide range of crops (including rice) to be grown within the one irrigation system without needing to re-landform or change banks. Water is delivered to each bay through the side ditch and is then either directed straight into furrows perpendicular to the side-ditch (Figure 9), or it is directed into field ditches at either end of the block before it runs into furrows parallel with the side-ditch (Figure 10). In the first of these systems, the furrows may only be watered from one end and there may be a rising slope (approx 1:10,000) in the direction of water advance to facilitate drainage back into side-ditch. If furrows are watered from both ends, then the bay has zero slope in both lateral and longitudinal directions. As with many basin systems, the first and last bays are made half size: the first to build a head of water and the last to take the tail water from the second last bay to avoid tail-water run-off.
Advantages

- labour savings over conventional graded furrow systems (no syphons to shift).
- ability to wet over the top of raised beds in non-subbing soils
- potentially greater distribution uniformity and higher irrigation efficiency
- potentially very short opportunity times: e.g. watering-up of sweet corn (R. Commins, pers. comm.). See also Quarisa (2003)
- good water depth control for rice
- extremely flexible system which can be used to grow a very wide range of crops
- vastly improved machinery efficiency
- easy to automate: e.g. I. Blight (Quarisa 2003)

The advantages of these systems are well described by Beecher, et al. (2005)

Disadvantages

- generally require high flow rates
- specialised bed forming and row cropping machinery required
- not considered compatible with livestock enterprises

These disadvantages mainly relate to the nature of rice based mixed farming enterprises in the Murray Valley, a general desire to minimise costs and to the constraints on maximum flow rates available to irrigators on MIL supply.

Figure 9. Representation of a level furrow system with furrows perpendicular to the side-ditch.
Figure 10. Representation of a level furrow system with furrows parallel to the side-ditch.
6. Irrigators’ considerations when designing “new” basin systems

Nearly all participants in the group discussion sessions were considering upgrading or changing layouts in the near future. Most participants, though not all, said that they used an irrigation designer when planning new layouts (50% to 75% of each group did). Nearly all irrigators interviewed said that they discussed their plans with an earthmoving contractor.

The fact that many basin layouts in the Murray Valley are not best hydraulic design (i.e. opportunity times > 15 hours) indicates there are factors of greater importance to irrigators than strict engineering criteria. These factors need to be understood to ensure that recommendations from this project are relevant and therefore adopted. All irrigators interviewed were asked what factors they considered when designing and installing a new layout. The responses were generally common to all groups. In summary, irrigators wanted new systems that allowed greater cropping flexibility and higher returns, were not costly to install, fitted with lifestyle considerations and which increased labour/time efficiency.

Their responses indicate that criteria additional to standard engineering measures are required for defining “best practice” design for basin irrigation systems.

6.1. Which paddocks are upgraded first

Irrigators interviewed stated that paddocks were selected for upgrading because they:
   a. had better soil types and also (possibly) better drainage
   b. were more productive (i.e. highest yielding) paddocks
   c. were the easiest to upgrade (i.e. not broken slopes, no tree lots)
   d. were closest to the wheel and recycle system

A number of participants chose to upgrade their “worst” layouts first. For example, one participant preferred to convert layouts with small bays and steep slopes into terraced layouts. However, even in this case it would appear that the paddocks selected for upgrading are those that are considered to produce the greatest net benefit to the farm business.

Marshall (1993) found that the greatest economic gain was likely to come from landforming the paddock which required the least earth-moving and when water was limited, the rate of return from landforming the last paddock was significantly less than that for earlier paddocks. Additionally, Young (1989) noted that there is a greater potential to recoup the costs of landforming when irrigation intensity is higher (i.e. more water available per developed area), as it is in the Murrumbidgee Valley. Low allocations will have a similar effect.
6.2. Factors considered in selecting the “best” design

The factors considered by irrigators are described in priority order.

1. Nature of the enterprise
   Paddocks must be “multi-use”, particularly if stock are part of the enterprise mix. Rice is currently the “best” crop and layouts must suit rice. Consequently, flat grades are desired for good water depth control. The ability to grow a wide range of crops is desired so the crop that makes the most money can be grown. The majority of irrigators matched the enterprise or crop to soil type – i.e. basins on rice country and rest of the property in border check.

2. Minimise the amount of soil shifted and use natural slope
   The aim is to minimise landforming cost and the depth of cuts. The factors considered are slope (angle and continuity) and topsoil depth, which determines maximum depth of cuts.

   There were divergent attitudes between the groups regarding “topsoiling”. All groups recognised the long term (> 20 year) loss of productivity from cut areas but only some groups felt that the additional cost (of top-soiling) was worth the future cost of lost production (plus the added, long term cost of ameliorating these areas).

3. Cost of Structures
   For many, decisions regarding layouts are based on minimising the initial cost (i.e. fewer and smaller structures). Some groups recognised that it was better to pay more initially because of the time/labour savings gained in the long term (e.g. access, no shovelling, no pulling down/putting up banks).

   The preferred choice is concrete structures, but there was no consensus as to which sort was the best and many felt that structure design could be improved. Overall, there was recognition that structures need to be designed for high flow rates.

4. Access
   a. **Vehicle access around all sides of the paddock** is preferred for crop inspection, controlling ducks, checking progress of an irrigation (needs to be easy to do, particularly on flat grades), and for (big) trucks for grain transport

   b. **Vehicle access into the paddock** ("cross-overs") on supply end and preferably into both ends of the bay. These shouldn’t cross a drain and cut drainage lines and, for this reason, permanent structures were considered best. These should be good enough to not need to slow down in a vehicle. Some try to avoid pipes because of the cost but others preferred them. It was noted that a pipe and head wall is needed to drive over a side-ditch.

   c. **Vehicle access between bays** inside the paddock is desirable for checking and moving stock (this is a key consideration for mixed croppers/graziers) and at harvest time for the chaser bin.
5. **Bay size and shape**

   The key factors dictating irrigator's choices of bay size/shape were:
   - supply flow rate – 3 to 4 ha bays appear to be standard with MIL supply
   - lifestyle considerations - designed for 12 hour watering
   - potential for wind damage – long access of bays oriented to minimise wind
damage to establishing rice in spring

   Machinery is larger now and contractors charge for the area covered. Farmers are
trying to reduce costs by going for bigger bays (which require higher flow rates),
less turning, straight lines (squared-up bays or banks that are at least parallel) and
bay widths that are a multiple of machinery widths (i.e. less overlap).

6. **Other factors**

   - Distance from the wheel and recycle system
   - Minimise drainage/tail-water coming off the paddock. Drains take a lot of water
to fill and tail water needs to be pumped.
   - Large weed free drains
7. Irrigation designers requirements

7.1. Information to aid the design process

The irrigation designers interviewed requested two “types” of information:

1. Hydraulic data to support the irrigation design process.
   - Manning’s roughness coefficients ($n$) for within bays and in channels and drains
   - characteristic soil hydraulic properties.
   - performance characteristics of “new” design elements, particularly side-ditches and terracing.

2. Data to support an economic analysis of alternative irrigation designs that could be presented to clients to show them the full costs and benefits of each alternative. The information should include:
   - agronomic data such as average yields with good drainage, maximum duration of ponding and predicted losses due to waterlogging;
   - expected improvements in returns to water, land, labour and capital and comparative times needed to pay for the works done.

The designers commented that many irrigators go for the cheaper cost options at set up and this ends up costing in performance of the design. Those interviewed felt there is a need for the project to quantify this “cost”, either in terms of increased labour, poorer machinery performance and/or lost income.

The Focus Group identified two issues related to the information required by the designers that they felt the project would need to address:

1. **variability in soil infiltration rates.** Some irrigators felt that the project would need to address this issue and that covering the range needed would be impossible. The Designers in the group felt that variability in infiltration rates made little difference in the field in the time taken for water to get onto and off a paddock.

2. **variability in preferences and poor economic circumstances** of many irrigators in the district. Participants felt this resulted in differing attitudes to change amongst irrigators and could affect the willingness of many farmers to take up new technology. Additionally, it was also felt that a “one size fits all” solution was not likely to be successful.

The following quote from Clemmens (2000a) regarding conversion of graded border to level basin systems in the USA is insightful given the comments above:

"Regulators and action agencies tend to have a one-size fits all mind set, giving the impression that it is almost always appropriate to convert to level basins and that such conversion will always lead to improved efficiencies. On the other hand, farmers tend to make conversions without doing their homework. We have experienced many cases where farmers convert to level basins and don’t change the way they irrigate, resulting in gross over application. Low available flow rates also limit the size of basins and thus economic feasibility."
7.2. Design models and software

In Attachment 1 of this report, Gillies et al. (2007) examine a range of simulation models for their potential use with basin systems. These include SIRMOD (Walker 2003), SRFR (Strelkoff, et al. 1998) and CoBaSim (Khanna et al. 2003b; Khanna et al. 2003c). They concluded that none of these models are currently able to simulate the basin systems found in the southern Murray Darling Basin. CoBaSim has the greatest applicability, but the software is unsupported and unusable and infiltration and roughness can not be obtained by inverse modelling of field data. SRFR can cope with a number of field layouts and is used as the basis for basin design procedures in the U.S.A. but it requires validation in local layouts. (see Attachment 1 for more detail)

Clemmens (2000b) differentiates between models used for simulation and those which can be used for design. To develop best design or operation recommendations, repeated simulations with different conditions are required to arrive at some optimum choice. These have been performed and incorporated into BASIN (Clemmens, et al. 1995) to provide design guidance for single, regular shaped, level basins with no outflows. Whilst BASIN is not suited to irregularly shaped, interconnected contour basins, it does provide an example of the type of program that irrigation designers said they wanted.

All designers interviewed had been exposed to CoBaSim during its development and their experiences informed their opinions as to directions for this project. They all commented that CoBaSim was not simple or easy to use and that there was no technical or software support beyond the life of Khanna’s project. Most had tried the program, but none had been able to use it. All those interviewed wanted a simple design model that had good technical and software support and which was capable of determining optimum bay size (width or length) given supply flow rate, soil type, roughness and an opportunity time that suited the most waterlogging sensitive crop. Ideally, it would also be able to be used with field data to determine infiltration and surface roughness by inverse modelling.

Khanna & Malano (2006) concluded from their review of basin irrigation models that:

- two-dimensional rather than one-dimensional models are required to simulate all the flow processes involved in contour basin irrigation events; and
- accurate values of Mannings n and infiltration coefficients are needed and are best obtained by inverse modelling using field observations of water front advance.

They note that no simulation model (including their own CoBaSim) is able to calibrate infiltration or surface roughness from field data with 2-D flow and they state that further research is needed to enable a 2-D model to do this.
7.3. General indicators of good basin design

In general, Swinton’s recommendations for good basin design matched irrigation designer’s concepts of “best practice”. The designers general “rule of thumb” was that bay size in ha should be roughly a quarter of the supply flow rate in ML/day (P. Price, pers. comm.). This assumes that a single irrigation event in a basin system uses 1 to 1.5 ML/ha for far-levee soils in the Riverine Plain (M. McBurnie, pers. comm.; Rahman 1994). For example, if a basin is covered in half the opportunity time (U.S. Natural Resources Conservation Service 1997) then, for a desired opportunity time of 12 hours, a supply flow rate of 12 ML/day is required to irrigate a 3 ha bay. The information requested by the designers will provide more rigour to these rules of thumb.

One of the key design criteria is the maximum opportunity time required to avoid waterlogging losses in the most sensitive crop. This information is currently not available. It is noted that this information was not requested by the irrigation designers, whose focus was engineering criteria, nor by the farmers interviewed, whose primary considerations were cost and lifestyle factors.
8. Tools to evaluate basin systems

The commercial Irrimate™ in-field evaluation service, as used in furrow irrigation systems, typically uses a siphon flow meter, six water advance sensors and an RBC in-furrow downstream flume to evaluate irrigation efficiencies. Soil moisture deficit at irrigation is estimated from crop water use estimated from climatic data and the Modified Penman-Monteith equation (Raine et al. 2005). Gillies et al. (2007) found that this methodology is not suited to basin systems and the following discussion reviews some alternatives.

8.1. Soil moisture

Malano & Khanna (2001) took gravimetric samples for estimation of pre and post irrigation soil moisture. The use of climatic data and the Modified Penman-Monteith equation for estimating soil moisture deficit at irrigation (as per Irrimate) is more cost effective but introduces too much uncertainty into field evaluations. It may be accurate enough for a commercial in-field evaluation service for basin systems, but this would need to be assessed.

8.2. Inflow rates

Typical inflow rates reported by those interviewed were from 10-12 ML/day for paddocks supplied by one Dethridge wheel; 20 ML/day for two Dethridge wheels or one wheel supplemented by recirculation system pump; and 30-40 ML/day (up to 60 ML/day) for river pumpers. These sorts of flows are applied to whole bays through regularly shaped structures. Siphon flow meters, as used in the Irrimate™ system, are not well suited to measure inflows in the circumstances commonly encountered in basin systems in southern NSW.

8.3. Advance and/or depth sensors

Advance sensors detect when the wetting front reaches a point and allow the rate of wetting front advance to be determined. However, they do not allow estimation of either the water surface profile or the surface volume to allow independent determination of the infiltration function and surface roughness. Nor do they measure opportunity time.

The key performance indicator of basin irrigation design in southern NSW is opportunity time because it directly affects the major cause of low water productivity in these systems (i.e. waterlogging and excessive deep drainage). Sensors/loggers are needed that measure the depth of water ponded over the bay for volume balance calculations and for determining advance and recession rates.

Capacitive water level sensors have been used by a number of workers in studies in irrigation districts of the southern Murray-Darling basin (Hume 1993; Austin & Prendergast 1997; Khanna et al. 2003b; Khanna et al. 2003c; Hornbuckle et al. in press). These sense water depth at pre-determined intervals and store this data for later retrieval. There are other methods (e.g. double bubbler method of Clemmens et
al. 2003; pressure transducers or ultrasonic sensors) but capacitive water level sensors have the advantage of being stand-alone units that are relatively cheap and accurate, allowing any more points to be measured simply and without the need for cabling.

With all methods it is necessary to survey the soil surface and sensor elevations at each point of measurement in the field. Clemmens et al. (2003) measured these before and after irrigation to obtain an average soil surface elevation at each point. The location of each feature, each sensor/logger and the wetting front can be accurately mapped using differentially corrected GPS measurements.

8.4. Flumes and flow meters

There are two methods of measuring open channel flow:

- weirs and flumes, which presume that the instantaneous flow rate can be determined from a measurement of flow depth; and
- flow meters, which derive flow rate from measurements of flow velocity and water depth through a regularly shaped structure.

The typical basin layout in southern NSW comprises bays graded to the plane of best fit with a slope of 1:1500 to 1:2000 and contour intervals generally no greater than 5-7 cm. The primary problem with using weirs and flumes in these layouts arises because water backs up and drowns them. Raised sill flumes are not suitable because they affect flows or become submerged if there is insufficient fall between bays. Width contracted flumes have the advantage over raised sill flumes of operating with sufficient accuracy up to 60% submergence. Long-throated flumes and broad-crested weirs are usually the most economical of all structures for accurately measuring open-channel flows, but conditions are often such that a weir or flume is not feasible.

If used, conventional flumes would need to be large to handle the expected flow rates (20-40 Ml/day). This makes handling, transport and levelling difficult. Local experience with a large raised sill flume designed for shallow drains is instructive (Phil Price, pers. comm.). The flume was unwieldy, very difficult to get level in both directions and impossible to remove from wet drains following an irrigation event without using the winch on a vehicle. Furthermore, it was often unsuited to measuring drainage flows because flat grades caused it to become submerged.

Hornbuckle et al. (in press) outline an approach using a modified version of the circular (width contracted) flume described by (Samani 1991; 1994) for the measurement of water flows at the paddock scale. The authors describe the dimensions and sizing of circular flumes (Figure 11) for the measurement of a range of typical water flows in flood irrigation layouts and make recommendations on the use of such flumes in field situations. The methodology offers the following benefits:

- low cost, easily constructed and easy to transport
- lower head loss than RBC flumes (Clemmens et al. 1984)
- the ability to continuously record flow using low cost water level sensors
- the light construction makes installation and removal a simple operation and the circular profile makes levelling the flume both easier and less critical.
The circular flume has a submergence ratio of 0.8 and may be well suited to measuring flows in individual furrows. However, it is not suited to measuring flows where water may back up and drown the flume. In these situations, a flow meter placed in a regularly shaped structure should provide more reliable measurements. In their evaluation of basin systems, Malano & Khanna (2001) used Starflow™ Ultra-sonic Doppler flow meters installed in rectangular wooden flumes placed at inlet/outlet structures, with discharge determined from velocity-area calculations. To back up these measurements they measured water depth in the wooden flumes with capacitance depth loggers and periodically checked flow velocity with a current meter.

Doppler flow meters have a pressure transducer to measure the depth of flow, enabling the cross-sectional area of open channels to be determined. The combination of velocity and depth measurements permits these meters to measure flows in all situations likely to be encountered in the field: full pipes (pressurised and gravity fed), partially full pipes and open channels. No other method has this capability with the following advantages (Naturally Resourceful Pty Ltd 2003):

- High degree of accuracy (<1%±) and consistent over full flow range
- Robust with only minimal routine maintenance required.
- Capable of measuring bi-directional flow
- Simple to install
- Same meter can be used in a wide range of pipe sizes and open channels

8.5. Calibration of flumes, flow meters and structures

It is clear from the farmers interviewed that most layouts have regular shaped inlet and outlet structures. These are either pipes or concrete stops. For ultra-sonic meters to measure flows precisely and accurately, then stable flow conditions will need to occur
through these structures. This should be straight forward in pipes, though experience suggests that drop inlets entrain air and pipes may not be long enough for stable flow to become established (the ideal piping requirement for ultrasonic meters is 6 pipe diameters upstream and 2 down-stream; Naturally Resourceful Pty Ltd 2003). Variable flow conditions through concrete stops can be standardised using a rectangular flume such as that used by Malano & Khanna (2001).

Vermeyen (2004) evaluated the accuracy of Starflow™ Ultrasonic Doppler meters and found that they measured velocities that were consistently 24% greater than average channel velocity in a rectangular flume. This was attributed to the fact that the Starflow instruments are calibrated in tow tanks, so the calibration is not representative of open channel or pipe flow where the velocity changes with distance from the boundary. The consistency in the percentage error suggests that the Starflow meter should have a stable calibration over a range of flow depths and Vermeyen (2004) recommended site specific calibration.

Calibrating Doppler flow meters for each site would make a commercial evaluation service too costly. Rather, it is recommended that the conditions in which the meters are used be standardised and that the meters are calibrated for each of these standard conditions. The following three standard conditions are suggested: pipe full flow under pressure from a pump; partially full pipes; and open channel flow through a standardised rectangular flume similar to that used by Malano & Khanna (2001).

### 8.6. Additional resources

[ANCID “Know the Flow” website](http://www.ancid.org) has information on flow metering equipment selection and operation

[WinFlume website](http://www.wiflume.com) has Windows-based computer programs to design and calibrate long-throated flume and broad-crested weir flow measurement structures
9. Discussion

There are very good reasons for the prevalence of basin systems in the irrigation areas and districts of southern NSW. No other irrigation application system is as well suited to the flat topography, low permeability heavy clay soils and the comparatively low reliability of supply in these gravity irrigation schemes. In addition, irrigation efficiencies of 85% are achievable with well set up layouts. These reasons comprise the key strengths of basin systems and, despite the impact of the national water reform agenda and the recent drought, they remain valid and relevant. On the other hand, their key weaknesses are their propensity to waterlog, which restricts productivity in the non-rice phase of the rotation, and the restrictions to access created by high contour banks. In thinking about improving basin systems then, it will be important to build on their strengths and overcome their principal weaknesses.

There is a fundamental problem to overcome before this can be achieved. Waterlogging in basin systems occurs as a result of two different but related events:

1. excessive irrigation opportunity times resulting from
   a. slow advance rates and
   b. slow recession rates; and
2. inadequate drainage following periods of excess rainfall resulting from
   a. limited soil water storage and low saturated hydraulic conductivity and
   b. slow recession rates.

Bay size affects both advance and recession times and increasing it to increase operational efficiency compromises hydraulic efficiency and increases the risk of waterlogging. There is thus a conflict between best hydraulic design as recommended by irrigation designers and the most economic design asked for by irrigators.

Current design recommendations are primarily aimed at deriving the best hydraulic design. Swinton’s recommendations were based on district experience and have been generally accepted and adopted by local irrigation designers and irrigators and this was reflected in the interview responses. However, these recommendations are now nearly 20 years old and they do not meet the current need for designs with both improved hydraulic and operational efficiency. Because of this, irrigators have been doing their own experimentation to find better basin designs and this is evident in the installation of “non-standard” designs over the past few years.

There are, in general, no design criteria or recommendations available to guide this development into the future. The work on drain-back level basins in the U.S.A. and the design recommendations based on SRFR may be directly applicable to similar designs being installed here. However, with respect to contour basin and level furrow systems, the US experience and design recommendations appear to offer little assistance.

Khanna and Malano made a number of recommendations regarding design and operation of contour basin systems but did not examine level basin or level furrow systems. Whilst they did address the need for better design information for contour basins, their recommendations are flawed in a number of respects. Firstly, they concluded that unit inflow needed to increase more than proportionally with an increase
in aspect ratio. However, they only modelled an increase in aspect ratio by increasing the width of a basin which had side-fall (i.e. lateral slope). Their finding is a natural consequence of the resulting increase in the minimum ponded depth needed to cover the bay. The effect of altering bay length and holding bay width constant also requires examination.

Secondly, Khanna et al. (2003a) state that it is common practice among designers to provide some slope in the longitudinal direction, with slopes between 1:3000 and 1:1250 being common. For a 300 m long bay, this would result in a 9 to 24 cm difference in height between the two ends of the bay and present great difficulties for rice establishment. Their statement is erroneous and it is highly unlikely for basin layouts used to grow rice to have slope in the longitudinal direction.

Finally, they concluded there was no benefit from increasing the terrace between basins. This is at odds with district experience. They used a roughness coefficient ($n$) of 0.05 (for bare, cultivated soil) in their simulations and the model basin had slope in both the longitudinal (1:20,000) and lateral (1:3,300) directions. The low $n$ and the slope would have hastened wetting front advance in the second bay, thus reducing the likelihood of water backing up and slowing drainage from the first bay. Furthermore, a minimum step of 5 cm was used as the “control”. A more realistic “control” would have been to use adjacent bays constructed along the plane of best fit (i.e. with side-fall), with no terrace, no slope in the advance direction and $n = 0.25$ (i.e. pasture and crops with drill rows perpendicular to the water flow). The effect of terracing should then have been assessed by setting the side-fall to zero and increasing the bay width to achieve greater vertical displacement and comparing this to the “control”.

Despite the lack of available design models and software for basin systems, it is still possible to appraise the merits of basin design using hydrological principles:

1. **Advance** - Advance rates are primarily influenced by inflow rate, the surface storage volume, antecedent moisture content and final infiltration rate. Surface storage volume is a function of bay size and the minimum ponded depth. Anything that speeds advance will reduce opportunity times and improve distribution uniformity and irrigation efficiency. Slope in the advance direction and surface roughness have only a minor effect on advance (VIRASC 1985).

2. **Recession**
   a. **Drainage of excess rainfall** - The ability to shed excess rainfall is determined by recession rates off the bay. This is primarily influenced by the slope and surface roughness of the bay and the down-slope distance to a drain (length of run).
   b. **Drainage of irrigation water** - The ability to drain quickly following irrigation is influenced by the drainage rate off the bay, the volume of surface storage to be drained, the outflow rate from the bay, and the advance rate and ponded depth downstream of the bay being drained.

When these principles are applied to natural contour systems (Section 5.1.1) it is very clear that there is little reason for irrigators to continue using them. It was apparent
from the discussion group interviews that many irrigators are planning to upgrade their
old layouts. However, there were also many cases where this was not being
considered or where the cost of upgrading these layouts was considered un-economic.

Some basic principles of good design are well accepted:

- laser grade to remove high spots and reverse grades
- landform to minimise channel, drain and contour bank lengths
- avoid permeable soils under channels, drains and rice areas
- install drainage recycling and re-use systems
- use high flow rates with correctly sized and installed channels and structures.

These principles are reflected in the three permutations on conventional lasered,
parallel contour designs (Sections 5.1.2, 5.1.3 and 5.1.4). Whilst these can be
considered current best practice design for contour basins, it is clear from the
discussions for this study that irrigators wish to improve the performance of these
designs. The principles outlined above suggest that this should be possible and the
primary means will probably be to increase flow rates. However, other options to speed
wetting front advance and improve winter drainage also need to be examined (e.g.
Clemmens grid of spinner cuts, large toe furrows) as do the conditions (i.e. surface
storage volume, slope, roughness, number and size of outlets) under which side-
ditches are effective.

Level furrow systems (Section 5.3.2) offer one way of improving both the hydraulic and
operational performance of basin systems. However very few irrigators in the Murray
Valley appear prepared to adopt this technology. Whilst these systems have undoubted
advantages, it is appropriate to bear in mind the recommendation of the Focus Group
against a “one-size-fits-all” solution. There are very real reasons why Murray Valley
irrigators are reluctant or unlikely to adopt this technology. It will be important for this
project to obtain the data and develop the tools to help irrigators make well informed
decisions that suit their individual enterprises.

The development of “drive-over bank” systems (Sections 5.2.1 and 0) offers a
compromise that may better suit Murray Valley irrigators. Removing the restriction to
trafficking caused by the contour banks should allow the operational performance of
contour basin systems to be improved. The principle hydraulic advantage of Morona’s
design derives from being able to sow with the slope, thus greatly reducing surface
roughness and improving rainfall run-off. However, it may just be an evolutionary step,
as the Kooloos “V-bay” system appears, at least theoretically, to be a better hydraulic
design: surface storage is halved by the broken slope, bay slope is increased and
surface roughness is reduced. The “V-bay” also has operational advantages that other
contour basin systems don’t, making it a viable alternative to level furrow systems. For
instance, because the banks are on the high side of each bay they require less soil, are
easier to drive over, don’t require a road grader to pull them up and they are less likely
to crack through and leak water into the downstream bay during an irrigation (this is a
major consideration for many irrigators with cracking soils).
Some rice growers have adopted level basin systems (Section 5.3.1) in combination with high flow rates to increase hydraulic performance. The flat bays reduce the minimum ponded depth and shorten the time to cut off, as well as improving water depth control for rice. However, bay size is generally increased to improve operational performance and this may negate any advantage in hydraulic performance. Furthermore, the lack of slope was questioned by most irrigators interviewed because it was considered to increase the risk of waterlogging. Despite this, these systems may have a place as dedicated rice growing systems in areas where soil type precludes high levels of production from non-rice crops.

There is evidence in the literature to show that soil type has an effect on the duration of anaerobic conditions following an irrigation event. Setter & Watters (2003) differentiate between duplex, heavy clay and sodic soils and make the point that there is little or no field data that (1) characterises the timing and duration of waterlogging on heavy clay or sodic soils or (2) of soil redox potentials for crops waterlogged naturally by rainfall or irrigation. This is critically important information because the duration of anaerobic conditions following the cessation of drainage needs to be factored into the design opportunity time. This also has a bearing on the incidence of winter waterlogging and any recommendations for minimising this risk.

Permanent raised beds have long been advocated to reduce the impact of waterlogging and lift productivity. However, it is possible that adopting controlled traffic and minimum-till in Kooloos' “V-bay” may provide all the production benefits of beds if the soil is a duplex soil. Raised beds in level furrow systems may be required for high productivity on heavy clay soils and sodic soils may best be laid out to level basins and used as dedicated rice areas. This is merely conjecture at this point in time and requires investigation, but it does provide an alternative to the "one-size-fits-all" approach.
10. Conclusions

This study has highlighted the almost complete lack of basic data to support the design of basin systems. Knowing the maximum opportunity time of the crops to be grown in the rotation is possibly the most important piece of information required, yet there is a wide variation in recommended times (8 to 15 hours) and district practice is often more than double that recommended (24 to 48 hours). Furthermore, there is scant agronomic data to support the recommended times and there is evidence showing that these times should differ between duplex, heavy clay and sodic soils. Additionally, there is no readily available data on the infiltration characteristics of typical basin soils and no suitable simulation model which would enable its estimation using inverse modelling techniques. There is a body of literature regarding infiltration characteristics from the Murrumbidgee Valley and the Goulburn-Murray, but this needs reviewing to see how it applies and whether it can be used in the design process. There is also no published field data on the comparative performance of a range of basin designs which would allow a good comparison of alternatives.

Two major areas of contention concerned the efficacy of side-ditches and terracing. Information is needed to determine whether and under what conditions these reduce opportunity times. Evaluation of a range of simple methods that might speed advance and recession is also needed: e.g. spinner cuts, larger toe furrows, sowing with the slope as opposed to across it and alternative irrigation management techniques such as watering fields from the lowest bay to the highest or “skip” watering every second bay. Raised beds reduce the risk of waterlogging, but no studies were found that compared their ability to improve soil structure and reduce waterlogging with that from controlled traffic, stubble retention and minimum-till.

For many reasons, basin systems are developing differently in the Murrumbidgee and Murray Valleys. More extensive, lower capital cost systems are preferred in the Murray Valley, so contour basin systems predominate with pasture being a major component. Greater irrigation intensity and better soils in the Murrumbidgee Valley have seen cropping predominate and there is a major shift to drain-back level basins, either with or without raised beds. This difference needs to be accommodated in this study so that recommendations account for the differing nature of the agricultural enterprises in the two valleys. The experience of DPI Victoria staff in extending their AIMS model for border check systems could provide valuable insights and should be reviewed.

A significant area is still laid out to natural contour systems in the Murray Valley and there are good reasons why this is the case. However, with the expectation of lower and more variable irrigation allocations and a higher price for water, there is a need for data that shows the true cost of retaining these systems and allows realistic pay-back times for upgrading them to be determined. This data is also needed for other typical basin systems so that the benefit cost ratio and net present value curve can be determined when an upgrade is being considered (e.g. shifting from a conventional contour basin to a level furrow system). This data should include the expected (average and best) yield and water use production functions, fixed and variable
operating costs including labour and machinery times, and capital costs. The reluctance by many to topsoil paddocks was surprising, given over 20 year’s of landforming in the district. There is economic data regarding the benefit-cost ratio of topsoiling, but it is now quite old and needs to be updated and communicated more widely, particularly to earthmoving contractors.

Tools for evaluating in-field hydraulic performance of basins are available. Ultrasonic flow meters are recommended for measuring flows and capacitance depth loggers for measuring advance, recession and surface storage volumes. However, the flow meters may need site specific calibration and the minimum number of depth loggers needed to provide sufficient information for modelling and evaluation purposes is unknown. It is recommended that ways of “standardising” inlet/outlet structures be examined to derive a simple, reliable and accurate method of measuring flows with the ultrasonic meters. The minimum number of depth loggers required will need to be determined in concert with the development and refinement of an appropriate simulation model.

With respect to model development, irrigation designers specifically requested a simple model for determining bay dimensions (length and width) given supply inflow rate, soil type, surface roughness and slope. This should follow the development of a simulation model so that the optimum choice can be determined first and then built into the design model. Given the experiences with CoBaSim, it is also strongly recommended that the model chosen for development should be commercially available software that is and will continue to be supported. SRFR appears to be the better choice.

Given the importance of waterlogging in limiting the productivity of basin systems, it is strongly advised that the parameters used in any design model be for a “worst case scenario”. Thus, the maximum opportunity time should be based on the soil type and the most waterlogging sensitive crop and using the highest expected application depth and the highest expected roughness coefficient. No studies have been conducted to determine these parameters from in-field measurements for basin systems in southern NSW. The fact that there is no data to support recommended opportunity times for a wide range of field crops and that the current recommendations are blanket recommendations and do not differentiate between soil types is absolutely astounding. This is the key need identified by this study.
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