



## Border-check Irrigation Design

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*Border-check irrigation of perennial pasture can be quite efficient – on suitable soils, with an appropriate layout and good management.*

Efficient irrigation is applying the water needed by the pasture with a minimum of deep drainage or runoff. Irrigation efficiency can be quantified by the amount of the applied water actually used by the pasture (the **application efficiency**), and the “evenness” of the application (the **distribution uniformity**).

The design of an efficient border-check irrigation layout depends on many interrelated factors, including:

- the soil moisture deficit at the start of the irrigation;
- the soil infiltration rate, which is partly dependent on the soil moisture deficit;
- the slope of the bay;
- the length and width of the bay, and hence the area of the bay;
- the hydraulic roughness of the bay surface;
- the flow rate applied; and
- the time that it is applied for - the time of cut-off.

### Soil moisture deficit

This is the depth of water needed to “refill” the pasture rootzone to “full” (field capacity). The recommended best management practice for irrigating perennial pasture by border-check irrigation in the Shepparton Irrigation Region (SIR) is to irrigate after **50 mm of pan evaporation less rainfall (E-R)** has occurred since the previous irrigation. This is equivalent to about **40 mm of pasture water use**. *This is the target irrigation application, or the depth of irrigation needed to refill the rootzone.*

A higher soil moisture deficit (a greater E-R interval; resulting in a drier soil profile) will increase the depth of water taken up by the soil during irrigation. However, higher moisture stress in the pasture will reduce its water use and productivity.



*Figure 1 A border-check irrigation system must be well designed and managed to be efficient*

### Infiltration rates

For most SIR soils, infiltration is typically quite rapid initially, before stabilising at a relatively low constant rate.

The initial rapid wetting up of the soil is known as the *crack-fill* part of infiltration, and is largely dependent on the soil moisture deficit. Typically, crack-fill is about  $\frac{3}{4}$  of the soil moisture deficit, which for the above 40 mm soil moisture deficit is about **30 mm**.

The ongoing *final infiltration rate* typically ranges from less than 1 mm/hr for heavy clays to 5 mm/hr for fine sandy loams (see below), and is independent of the soil moisture deficit.

Considerable variability occurs with crack fill and final infiltration rate components, both between and within soil types, and within paddocks.

The infiltration characteristics of a given site can also change with time, subject to management. For example, a site that has not been irrigated for some years can develop cracks in the sub-soil which allow higher than expected infiltration rates, but these can slowly decrease with irrigation over a season or even longer as the sub-soil wets up and swells. Shallow watertables (say 0.5 to 1.0 m below the surface) can restrict infiltration, particularly in soils that would otherwise have relatively high final infiltration rates.

## Infiltration (continued)

A study of soil hydraulic properties in the SIR (Mehta and Wang, 2004) measured the final infiltration rate of the B-horizon subsoil, which determines the final infiltration rate of the soil. A summary is presented in Table 1.

**Table 1 Final infiltration rates for SIR sub-soils** (after Mehta and Wang 2004)

Infiltration rate classification	Typical soil type
High final infiltration rate > 5mm/h	<b>Group 1 soils</b> , such as Sandmount sand and East Shepparton fine sandy loam, Cobram sandy loam, but excluding Nanneella fine sandy loam
Intermediate final infiltration rate 3 to 5mm/h	Nanneella fine sandy loam, Waaia loam phase, Katamatite loam
Low final infiltration rate 0 to 2 mm/h	<b>Most SIR soils</b>

Ideally, bays should contain only one soil type, or at least, soils types that have similar infiltration characteristics.

*Soils with high final infiltration rates are generally not suited to border check irrigation.*

## Slope

This is largely determined by the site's topography, but can be altered by earthmoving.

Slope is important for drainage of excess water, particularly on medium to heavy soils. However, bays that are *too steep* can be prone to erosion and difficult to cover with water.

Slope affects the rate of the irrigation moderately, but has less impact on irrigation performance than the effects of infiltration rate, flow rate and bay length.

Table 2 shows slopes suitable for border-check irrigation.

**Table 2 Slopes suitable for border-check irrigation (from Rural Water Commission 1988)**

Slope		Suitability for border-check irrigation
Vertical : horizontal	Percentage	
Flatter than 1:1250	Flatter than 0.08%	- Not recommended, because of inadequate surface drainage
1:800 to 1:1250	0.125 to 0.08%	- Not recommended for perennial pastures; - Suitable for annual pastures, crops irrigated infrequently (limited drainage)
1:600 to 1:800	0.17 to 0.125%	- Suitable for perennial pastures; - Surface drainage may be poor on heavy soils
1:300 to 1:600	0.33 to 0.17%	- Optimal for perennial pastures
1:100 to 1:300	1.0 to 0.33%	- Suitable for perennial pastures; - Care needed irrigating bare soil; - Short bays may limit intake opportunity time on heavy soils
1:50 to 1:100	2.0 to 1.0%	- Inadvisable – short bays limit intake opportunity time; - Bare soil should not be irrigated because of erosion potential
Steeper than 1:50	Steeper than 2.0%	- Not recommended

## Bay length

Bay length is often determined by the topography, supply channel and drain infrastructure, or property boundaries. A *minimum bay length* of 300 m is generally recommended to facilitate farm management, although shorter bays can be efficiently irrigated and may be appropriate in particular situations.

The *maximum bay length* recommended depends on the final infiltration rate.

For most SIR soils with relatively low final infiltration rates, surface drainage following irrigation or rainfall is the major constraint to bay length. With higher infiltration rate soils, excessive infiltration and poor distribution uniformity are more important considerations.

## Bay length and flow rates

Table 3 (opposite page) is a guide to the optimum bay flow rates for typical bay lengths and infiltration categories. The values have been derived using the Analytical Irrigation Model (AIM) developed by Austin and Prendergast (1997).

## Flow rate and bay width

Normally, the design flow rate adopted is the highest normally available from the water supply, to maximise irrigation labour efficiency. Ideally, bays are designed to take the whole supply flow to maximise labour efficiency, minimise the number of farm channel structures and facilitate automation. Where the flow rate available exceeds that required for the selected bay width, two or more bays may be irrigated together.

**Table 3: Bay flow rates and application times for maximum efficiency and uniformity**

Bay length (m)	Final infiltration rate (mm/h)								
	Low (1 mm/h) most SIR soils			Medium (3 mm/h assumed)			High (6 mm/h assumed)		
	Flow (ML/d)		Time (h:m)	Flow (ML/d)		Time (h:m)	Flow (ML/d)		Time (h:m)
	per m width	<b>50 m bay</b>		per m width	<b>50 m bay</b>		per m width	<b>50 m bay</b>	
100	0.04*	<b>2</b>	2:05	0.06*	<b>3</b>	1:30	0.1	<b>5</b>	1:00
200	0.06*	<b>3</b>	2:55	0.1	<b>5</b>	2:00	0.16	<b>8</b>	1:25
300	0.08*	<b>4</b>	3:25	0.14	<b>7</b>	2:15	0.22	<b>11</b>	1:40
400	0.1	<b>5</b>	3:50	0.18	<b>9</b>	2:30	0.3	<b>15</b>	1:45
500	0.12	<b>6</b>	4:05	0.24	<b>12</b>	2:25			
600	0.14	<b>7</b>	4:15	0.3	<b>15</b>	2:25			
700	0.16	<b>8</b>	4:25	0.36	<b>18</b>	2:25			

Assumptions: - target application of 40 mm, crackfill of 30 mm  
 - surface roughness of 0.3 (see below)  
 - slope of 1:700, minimal runoff (1% to 3%)

\* Flows of less than 0.1 ML/d/m are generally not recommended because the shallow depth of flow makes full coverage of the bay difficult with even a moderate slope and good grading.

**Note:**

- The short application times for short bays (100 - 200 m) on low infiltration rate soils may allow insufficient infiltration. Lower flows (for longer application times) would exacerbate shallow flow-depth problems.
- Generally, soils with high infiltration rates are not recommended for border-check irrigation. While the 6 mm/h final infiltration rate soils assumed above can be efficiently irrigated, in practice high infiltration rates vary considerably and efficient, uniform irrigation is unlikely to be achieved.
- The light shaded values in the table are associated with ponding times of more than 12 hours, potentially resulting in excessive waterlogging. Higher flow rates do not significantly reduce this problem on the lower part of the bay, but may result in insufficient infiltration on the upper part of the bay.
- The non-shaded values (and the light-shaded values) have potential application efficiencies of 90% or better, where the dark shaded values have potential application efficiencies of 80% to 90%. Where no values are given, the achievable application efficiency is less than 80 %, and border-check irrigation is not recommended.
- For bays with widths other than 50 m, multiply the flow-per-metre value by the width of the bay to determine the recommended flow rate, or use Table 4 below.
- Where conditions are not as assumed above, the optimum application times for minimal runoff will be different to those shown. However, the flow rates shown are generally appropriate.

**Bay Width**

Table 4 gives the total bay width needed to achieve specified flow rates per metre width of bay with various supply flow rates. However, there are practical constraints on bay width and area:

- **The minimum bay width** is determined by the equipment used to construct the bay. Typically, a laser grader requires at least **30 m** width to operate efficiently, and this is generally recommended as the minimum bay width. However, 20 m may be practical with smaller equipment.
- **The maximum bay width** (see Table 5) is limited by the desirability of achieving full coverage of the bay from one bay outlet, and economically by the high cost of earthmoving likely to be needed to achieve very wide bays. The coverage from the bay outlet depends on the flow rate, the slope, and the depth of flow, which depends on the surface roughness.

**Table 4 Total bay widths (m) for various flow rates**

Flow per m width ML/d/m	Bay flow rate (ML/d)					
	3	5	7.5	10	15	20
0.05	60	100	150	200		
0.1	30	50	75	100	150	200
0.15	20	33	50	67	100	133
0.2		25	38	50	75	100
0.3			25	33	50	67
0.4			20	25	38	50

- The bay **area** (length x width) is ideally the required rotational grazing area or a multiple of it.

### Bay width (continued)

Table 5 gives recommended **maximum** bay widths for typical bay flow rates and slopes.

**Table 5 Maximum widths (m) for single-outlet bays**

Slope	Bay flow rate (ML/d)					
	3	5	7.5	10	15	20
1:700	40	70	85	100	100*	100*
1:500	30	40	50	60	80	100
1:300	20**	20	25	30	40	50
1:100	20**	20**	20**	20**	20**	20

\* 100 m is the widest recommended bay width

\*\* More than one outlet may be needed to ensure full coverage

The values have been derived using flow depths calculated from AIM, assuming a surface roughness (Manning’s *n*) of 0.2 (see below). Cultivated bare ground should be cross-harrowed to encourage full coverage.

### Surface roughness

The rate that water moves down the bay and the depth of flow on the bay depend partly on the density of the crop being irrigated; e.g. water moves faster and shallower through a stalky wheat crop than through a leafy dense pasture. This is not normally an issue considered by irrigation designers, but is relevant where an irrigation model (such as AIM) is used.

Surface roughness is expressed as “Manning’s *n*”; a roughness coefficient used in hydraulic design. For perennial pasture, Manning’s *n* values of 0.2 to 0.4 are common.

### Application time

This is the time interval that water is applied to the bay for, or the *cut-off time*. It is the time required to apply the volume of water needed at the design flow rate.

Application times of 2 - 6 hours are common. From Table 3, 4 hours is a desirable maximum (for 500m long bays on low infiltration rate soils). Shorter bays and higher final infiltration rate soils require shorter application times (see Table 3).

While some runoff is desirable to ensure that the whole bay is irrigated uniformly, too long an application time results in excessive runoff. While runoff is not wasted where it is collected in a drainage reuse system, excessive runoff (greater than say 5 – 10 % of the target application) is undesirable, as water is on the bay surface for longer than necessary, potentially resulting in excessive infiltration or waterlogging.

The time to cut off the flow onto the bay is normally judged from experience, perhaps fine tuned by knowledge of the soil moisture deficit, and by the observed rate at which water advances down the bay. Typically, the optimum cut-off time is when water has advanced to half or two-thirds the length of the bay.

The **intake opportunity time** is the time that free water is on the surface of the bay. It is longer than the application time, and varies along the bay. A good border-check irrigation design results in the opportunity time being relatively uniform along the bay and just long enough to allow the required depth of water to infiltrate. This results in a relatively uniform irrigation with little deep seepage.

### Runoff and drainage reuse

Collection and storage of runoff in a reuse system is essential for efficient irrigation. It is also critical for the effective management of nutrients to prevent them from leaving the property.

***While a border-check irrigation system can be potentially very efficient, it must be managed appropriately to achieve that efficiency and to achieve its potential productivity.***

### References:

Mehta, B and Wang, QJ, DPI Victoria (2004), Irrigation in a Variable Landscape: Matching Irrigation Systems and Enterprises to Soil Hydraulic Characteristics

Rural Water Commission of Victoria (1988), Irrigation and Drainage Practice

Austin, NR and Prendergast, JB (1997), Use of kinematic wave theory to model irrigation on a cracking soil. Irrigation Science 18, 1-10.

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