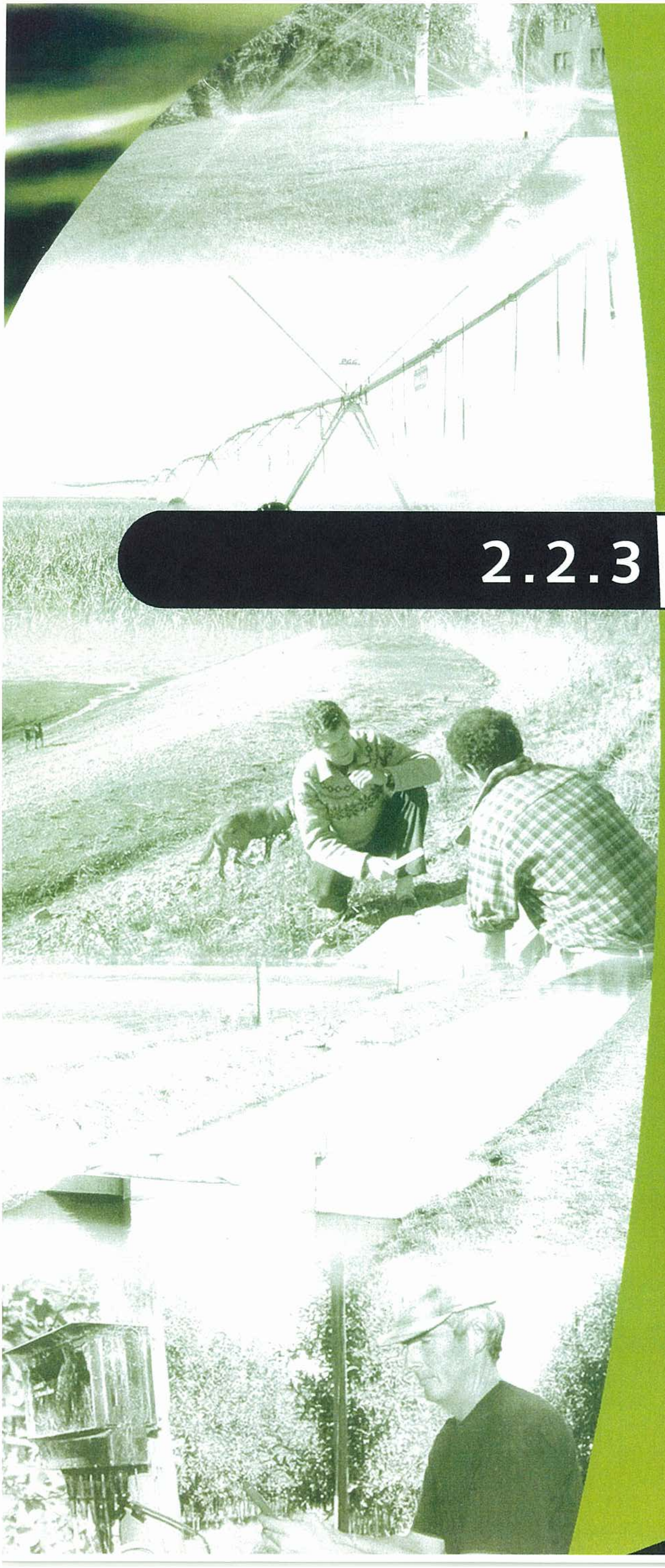


2.2.3 BORDER-STRIP

How to set up a border-strip irrigation system

The most important decisions about the set up of a border-strip irrigation system are made during the design and construction stages of border-strip development. Once the system has been built the only management option that is normally available to farmers is varying the irrigation time. In some circumstances it may be possible to vary the flow rate. Changes in set up, other than changing the irrigation time, generally require re-development of headraces or the border-strips themselves.

The depth of water that infiltrates the soil during a border strip irrigation event primarily depends on the:

- Infiltration characteristics of the soil (K factor)
- Slope of the border strip (metres fall per metre length of border strip)
- Length of the border strip (metres)
- Flow rate per metre width of border strip (litres/second per metre)
- Irrigation time (number of minutes the water is flowing over the sill)
- Roughness of the border strip (depends on how smooth the strip is and the height of pasture or crop).

The infiltrated depth of water is usually less affected by changes in the roughness than by changes in the other factors. Ideally a paddock would be well grazed at the time of each irrigation, but this is often impractical – for example when a paddock is shut up for hay or silage.

This information sheet assumes that the only management option available to the farmer is varying the irrigation time – that all of the other significant factors are fixed.

Most border strip irrigation systems in New Zealand are automated. Irrigation starts with the group of border strips that are furthermost downstream from the turnout or water supply, and proceeds upstream by sequentially closing headrace gates. This shuts the flow off from the currently irrigating group of border strips, and raises the water level in the headrace to the point where all of the flow is diverted over the sills to irrigate the next group of border strips. The closing of headrace gates is automated.

The most common method of automation is the use of clocks to trigger the closure of headrace gates. An alternative method is the pneumatic control system, which senses when the water has reached a set distance down the border strip and pneumatically triggers the release of the next headrace gate upstream. Once the pneumatic system is installed, all that is required to set the system is to raise the gates, connect them to the release mechanism, and ensure that the sensor is not already flooded.

With time-based automation, each clock is set to trigger after sufficient time has elapsed to, firstly, fill the headrace to the point where water flows over the sill (the start of irrigation for that group of border strips), and secondly, to adequately irrigate the border strips.

Historically, border strip irrigation development has occurred on soils with a high infiltration capacity (high K factor). On these soils the irrigation time that maximises irrigation efficiency is that which results in the water just reaching the end of the border strip. Under this situation all but the last few metres of the wetted strip generally receive enough water to restore the soil to field capacity.

The following graphs show the irrigation time that results in the water just reaching the end of the border strip, for different combinations of border strip length, flow rate, and infiltration capacity. These times do not include the time required to raise the water level in the headrace – the time from gate closure to the commencement of flow over the sill.

The graphs are based on the results of measurements made of irrigation performance in North Canterbury and Mid Canterbury. All graphs assume a slope of 0.006 metres/metre, which is typical of border strip slopes in Canterbury, and pasture that is about 100mm high.

To use the graph it is necessary to know the flow rate *per metre width of border strip*. This can be estimated as follows:

- Flow rate per border strip = Flow in the headrace / Number of border strips in the group
- Flow rate per metre width = Flow rate per border strip / Width of border strip.
- The flow rate in the headrace must be in Litres/Second.
- The width of the border strip must be in Metres
- To convert a flow expressed as cusecs to litres/second multiply by 28.3.

For example.

- Flow in headrace = 8 cusecs. Convert this flow to litres per second first.
  There are 4 border strips per group.
  Width of border strips is 12 metres.

- Flow in headrace in litres/second = 8 x 28.3
  = 226.4 l/s

- Flow rate per border = 226.4 / 4
  = 56.6 l/s

- Flow rate per metre width = 56.6 / 12
  = 4.7 l/s/m

- To use the graphs, this is approximately 5 l/s/m.

An approximate measure of K can be made by taking a 20 litre plastic paint bucket, cutting the base out, turning it upside down and inserting the top of the bucket into the soil deep enough to stop water leaking out around the edge. Five litres of water are then poured into this "cylinder" and the time it takes for all the water to infiltrate the soil is measured. The following table is then used to determine the approximate K value. The table assumes that the diameter of the top of the paint bucket is 250 millimetres.

Infiltration Time	K value	Infiltration Time	K value
415 minutes	5	86 minutes	11
288	6	72	12
211	7	61	13
162	8	53	14
128	9	46	15
104	10	26	20

To determine the irrigation time for a 300 metre long border, and a soil with an infiltration K = 10, draw a vertical line through the Length axis at the point marked 300 and find where this line cuts the 5 l/s/m curve. Draw a horizontal line through this point and across to the Irrigation Time axis. The point where this line cuts the Irrigation Time axis is the required irrigation time. In this example it is approximately 110 minutes.

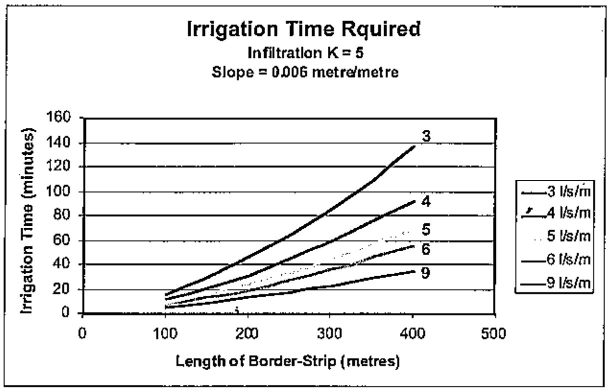
Three graphs are shown, each representing a different infiltration capacity that is identified as "Infiltration K = a number". The higher the value for K, the higher is the soil's infiltration capacity. The majority of border strips tested in Canterbury had a K value in the range 8 to 12.

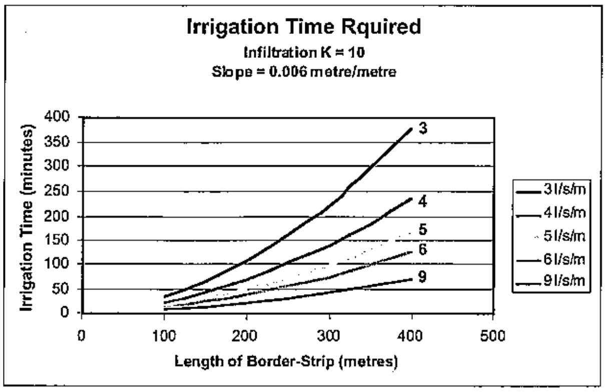
The irrigation time is very sensitive to changes in the K value. For example the irrigation time for a 300 metre long border and a flow of 5 l/s/m varies from about 45 minutes, for K = 5, to about 190 minutes for K = 15.

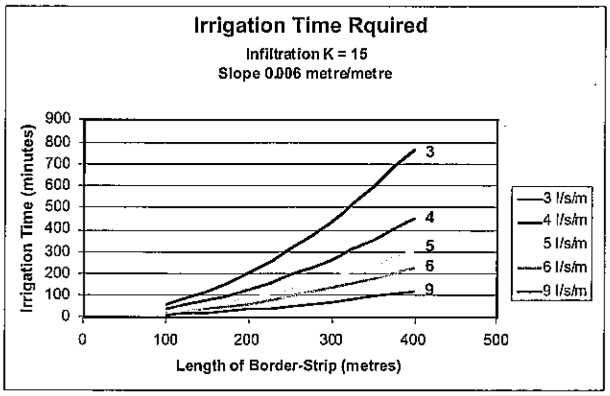
Unfortunately, the K value is often different for each border strip in a group, and this affects how long it takes to irrigate each strip. If the irrigation time is set for the average K value, some border strips will be over irrigated (water will run off the end), and others under irrigated.

Changing the flow going onto each border can even up the irrigation times for each border strip in a group. This can be achieved by adjusting the length of each sill. If all sills in a group are the same length (and elevation), the flow will be split evenly between the border strips. Changing the relative lengths of the sills will change the proportion of flow onto each border strip.

While the graphs in this information sheet provide some guidance on irrigation times, many factors work together to determine the irrigation time required to just water to the end of a border strip. Ultimately, achieving optimum results depends on observing what happens when each group is irrigated, and using the information gained to fine tune sill lengths and clock settings.







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How to change the depth of water applied

The main decisions that determine how much water infiltrates the soil during border strip irrigation are made during the design and construction stages. Once the system is built, the main management decision is the irrigation time required to just irrigate the full length of the border. This will minimise the depth of water infiltrated over the whole border and maximise irrigation efficiency.

How much water should be applied?

The amount of water that should be applied during irrigation is the amount needed to just return the soil water content to field capacity. In order to maximise production, it is necessary to irrigate before the critical deficit is reached (see Section 2.2.1). If the critical deficit is 50% of the maximum level of plant available water, then for many border strip irrigated farms on shallow soils, the soil water deficit at the time of irrigation should not exceed 30 to 45 mm. During summer this means irrigation return periods of 7 to 12 days.

When can the depth be changed?

The time to make changes that will reduce the depth of water that infiltrates during border strip irrigation is when the system needs re-bordering. The factors that have the most impact on the depth infiltrated are the length of the border, the flow rate per metre width of border strip, and the soil's infiltration capacity. Changing any of these involves a certain amount of reconstruction.

What changes need to be made to change the infiltrated depth?

The following charts show contours of the infiltrated depth of water, in relation to the length of the border strip, the flow rate per metre width of border strip, and the soil's infiltration capacity. These charts show that the infiltrated depth of water can vary from about 30mm, for soils with low infiltration capacity, to more than 200 mm for soil with high infiltration capacity.

All the charts assume that the slope of the border strip is 0.006 metre/metre, which is typical of North and Mid Canterbury, and a grass height of about 100 millimetres.

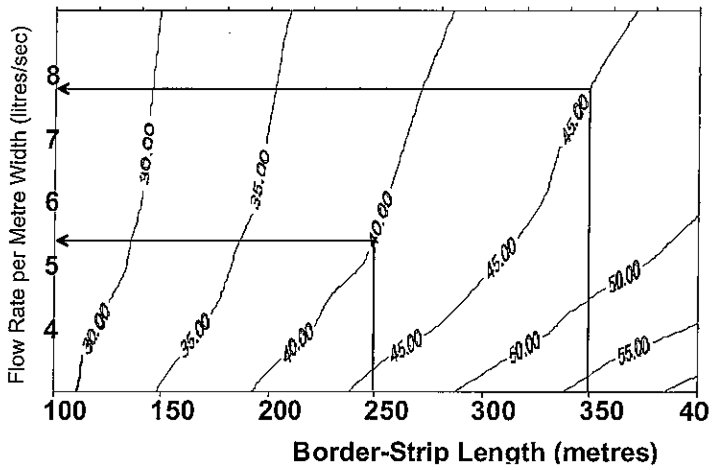
A method for getting an approximate measure of the infiltration capacity of the soil is described in Section 2.2.3, sheet 1.

If an infiltrated depth of water of 40 mm is required, and a border strip length of 250 metres suits the farm layout, the charts show that a flow rate of about 5.4 litres per second per metre width of border strip is required for a soil that has an infiltration K of 5. For a group of 6 border strips, each 12 metres wide, the headrace flow would need to be (5.4 x 12 x 6) approximately 390 litres per second. Two border strips, each 36 metres wide, would require the same headrace flow (5.4x36x2).

If K = 10 then it is not practical to achieve an infiltrated depth of less than about 60 mm.

The charts illustrate how sensitive the infiltrated depth is to changes in the soil's infiltration capacity. Compaction of the soil during re-bordering, to reduce the infiltration capacity, is an alternative to increasing flow rates or reducing border strip length. However, the degree of compaction required to achieve the desired change in infiltration capacity is, at this point in time, a matter of trial and error. How long the infiltration capacity stays at the modified level is also unknown. Natural biological activity may slowly increase the infiltration capacity over time.

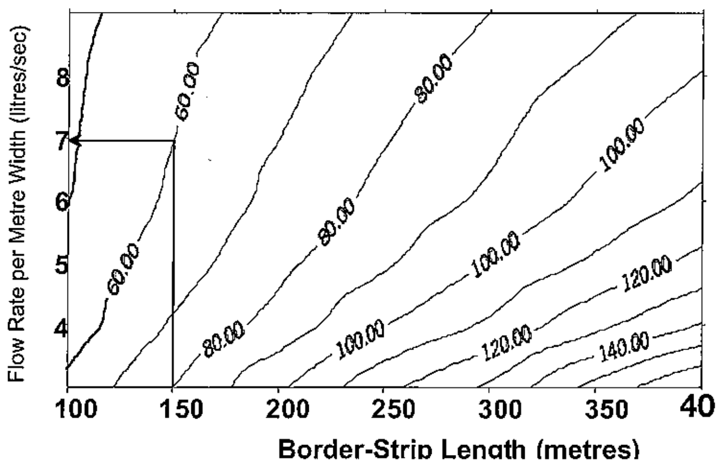
Average Infiltrated Depth Chart
Infiltration K=5



The average infiltrated depth is the same along any one line.

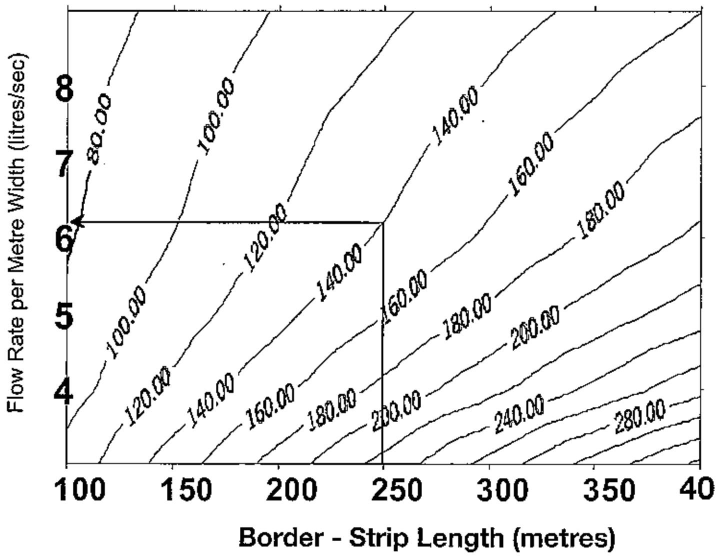
The chart to the left shows that if an average infiltrated depth of 40mm is required on a border 250m long, a flowrate of about 5.4 litres per second per metre width of border is required.

Average Infiltrated Depth Chart
Infiltration K=10



The chart to the left shows that a flowrate of 7 litres per second per metre width of border will enable an average infiltrated depth of 60mm to be achieved if the border length is 150m. As the length of border increases, so too does the average infiltrated depth.

Average Infiltrated Depth Chart
Infiltration K=15



How to handle water supply variations

Border-strip irrigation systems in New Zealand are designed to operate at a specific flow rate. Once the on-farm development is complete, it is expensive to change the design flow-rate. Maintaining a constant flow, both during an irrigation event and between turns on a rostered water supply, is very important for effective and efficient irrigation.

The flow rate per metre width of border strip is one of the key design parameters for border-strip irrigation application systems. The others are the infiltration characteristics of the soil, the length of and slope down the border strip, and the irrigation time. Once the on-farm works have been completed, the flow rate and the irrigation time are the only key parameters that can change, unless significant re-development is undertaken.

Many border-strip irrigation systems in New Zealand were designed for a turnout supply rate of 8, 12, or 16 cusecs (cubic feet of water per second). In metric terms this is approximately 230, 340, 450 litres per second (l/s). Assuming a turnout supply rate of 230 l/s, 6 bordered strips per group, and making some allowance for channel losses, the flow rate per border-strip would be about 36 l/s. The **following graph (FIGURE 1)** shows the time it would take to irrigate a 200 metre long border on a soil typical of Mid-Canterbury, given a flow rate of 36 l/s per border. It also shows irrigation times for flow rates smaller and greater than 36 l/s. The times given are those required for water to just reach the end of the border.

Also shown in this graph is the depth of water that would infiltrate the soil under these same circumstances. The graph shows that for a flow rate of 36 l/s, it would take 110 minutes to irrigate the border strip, and that 98 mm of water would infiltrate the soil.

If the system is set up assuming a flow rate of 36 l/s per strip, and the flow delivered is 32 l/s (11% decrease), **FIGURE 2** shows that the length of the border actually irrigated would reduce to 89% of the total length of the border. Reductions in flow rate therefore result in less area being irrigated, unless the farmer is on hand and can increase the irrigation time to compensate. Increases in flow rate, above the 36 l/s expected and set up for, result in water wasted through run-off. If the system was set for 36 l/s, but 40 l/s was delivered, the amount of runoff would be equivalent to a depth of about 6 mm of water over the irrigated area.

In summary, flow rate variations result in either lost production (flow delivered is low compared to the design flow) or water wasted (flow is higher than the design flow).

There is little a farmer can do, directly, to ensure that the flow received is stable during a rostered supply, or consistent between rostered supplies, other than ensure that the turnout is not blocked and that there are no major leaks from the headrace system.

Primary responsibility for achieving stable and consistent turnout flows rests with the irrigation scheme operators. If there are on-farm problems resulting from flow variations, these should be taken up with the irrigation scheme.

Figure 1

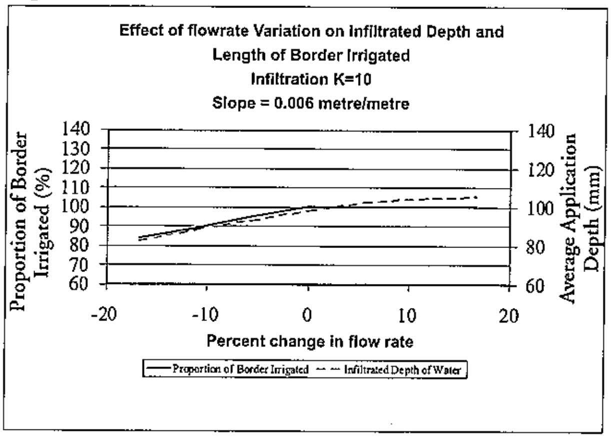
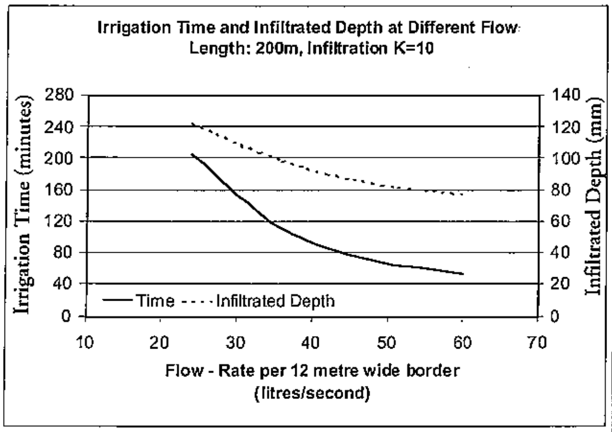


Figure 2



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How to avoid back-watering and over-topping

Back-watering occurs when the water level in the headrace is high enough to cause more than one group of border strips to be irrigated at the same time. This results in increased irrigation times because the flow rate per metre width of border is reduced.

Over-topping occurs when water flows over the levees (the ridges that define the border strip) or the headrace.

Avoiding both of these problems requires attention to detail during construction, and good, regular maintenance.

Back-Watering

A minimum of 100mm drop in elevation is required between the sills in adjacent groups of border strips. This assumes a headrace flow of up to 350 l/s, and sill lengths of at least 2.5 metres. This allows for the depth of flow over the sills of the irrigating group, and normal head losses in the headrace, and is designed to avoid flow occurring into the adjacent upstream group of border strips.

Once in use, it is important to keep the headraces clear of long grass and weeds, by regularly grazing them with sheep. As the height of grass or weeds in a headrace increases, so too does the headloss. Eventually the point is reached where the water level in the headrace is high enough to cause flow over the next group of sills upstream, which reduces the flow into the border strips that are supposed to be irrigating. In order to achieve sufficient grazing pressure to clean the headraces up it is usually necessary to fence off the headraces.

Fencing off headraces is essential if cows are grazed on border strips, in order to prevent treading damage to the headrace berms, and to the sills themselves. Damage to sills that reduces the elevation drop between sills in adjacent groups is another cause of back-watering.

Over-topping

The height of the levees decreases over time, as a result of compaction by animals and redistribution of soil during cultivation. Eventually the height of the levees reduces to the point where they are unable to prevent flow between one border strip and the next. At this point it is necessary to redevelop the border strips and reinstate the levees.

Over-topping of headraces and headrace structures is sometimes the result of poor construction, but usually a sign of poor maintenance. The risk of getting a poor job done can be minimised by engaging the services of a construction group that has earned a good reputation through delivering well thought out, well built border strip systems that have stood the test of time.

Over-topping resulting from the breakdown of headrace berms by animals can be prevented by fencing of the headraces, and grazing them occasionally with sheep.

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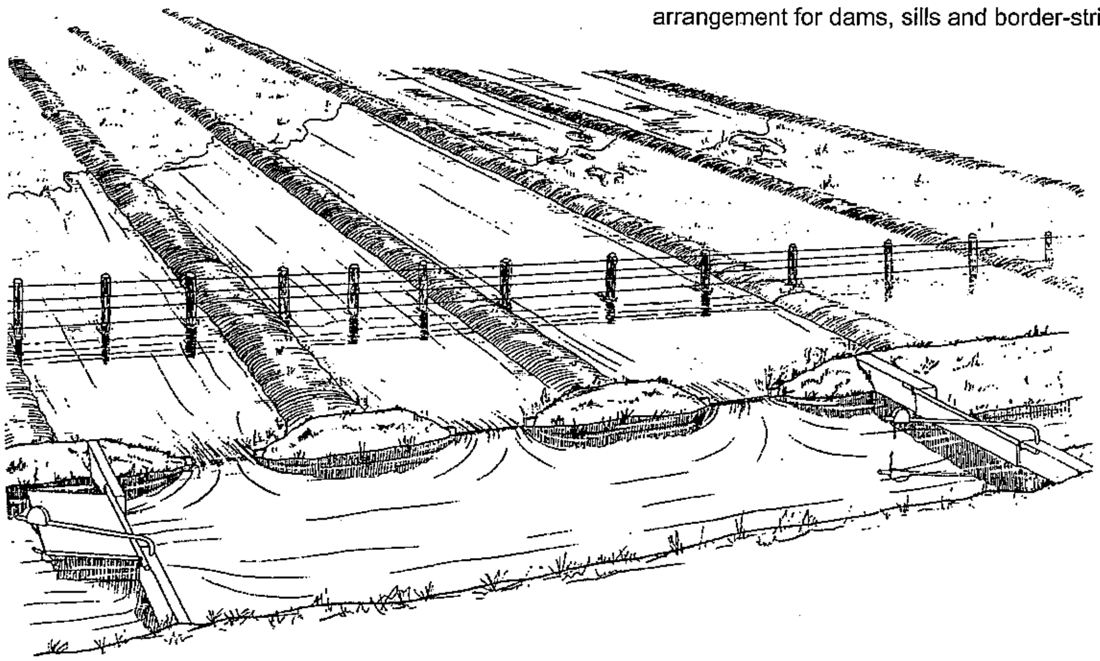
How to automate border-strip systems

It is now very unusual for a non-automated border-strip irrigation system to be installed in New Zealand. As a result of several decades of practical experience in constructing and operating automatically controlled border-strip irrigation systems, current systems are highly efficient in terms of labour and capital use, can be operated 24 hours per day, and are more economical in water use than manual systems.

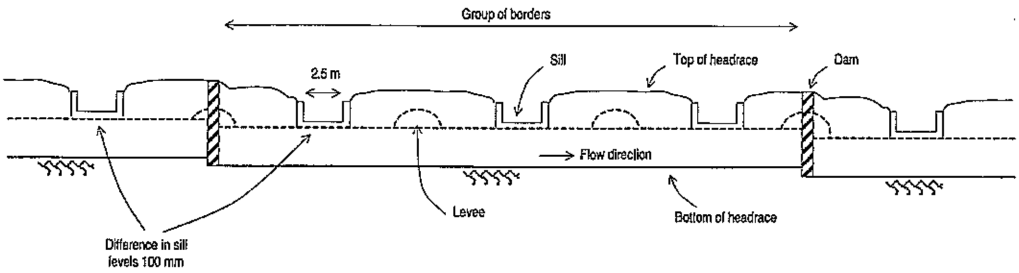
The following figure illustrates an automated border-strip irrigation system in operation. In this case three border-strips are being irrigated as one group. The water is impounded by the downstream gate, and watering of the group will occur until the next gate upstream is released to drop down and close off the dam. The release mechanism is usually a timing device, but sensor based systems are also available. Usually the farmer sets up the system once per day, or per roster period, by setting the timing device, lifting the gate up and hooking it onto the gate release mechanism. In some areas farmers are experimenting with automating the whole process – gate setting and releasing.

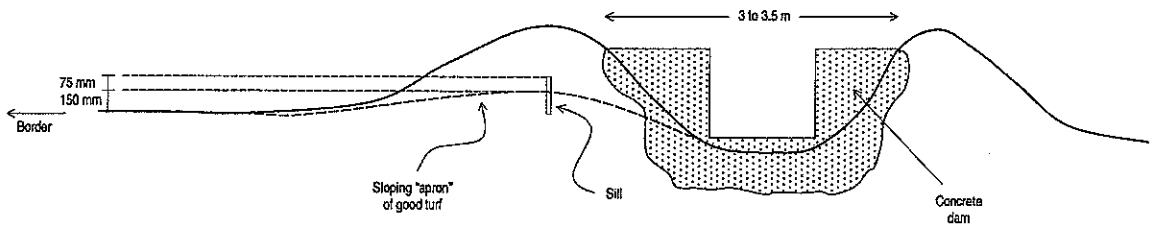
Figure - General layout of a group of borders with pre-set timers.



Head-race gradients are precisely determined and sets of between one and six border-strips, each fitted with one or more sills set at the same level, are irrigated at one time. Each group is separated from the adjacent group by permanent dams. Usually the dams are concrete, but other materials are sometimes used. When in use, the dams are fitted with light sheet steel gates that are operated by a timing device that closes them in succession, moving up-stream.

Effective and efficient border-strip irrigation requires a good construction team, for the earthworks involved and the setting out and construction of dams and sills. The sills in a group of border-strips must be set at the same level, and the sills in the next group upstream must be at least 100 mm higher. This difference in elevation is needed to allow for the depth of water flowing over a sill when it is in operation (about 60 mm for a 2.5 metre long sill and a flow of 350 litres/second), for the head lost as the water flows through the upstream dam, and for head losses due to channel roughness. The following figures show a typical arrangement for dams, sills and border-strips.





If the flow over a sill needs to be reduced because the border-strip it is supplying is watering faster than the others in that group, the sill length can be reduced. There will be a corresponding increase in flow going over the other sills in that group. The adjustment process is usually a matter of trial and error so it is best to not make the adjustments too permanent until you are sure you have the best combination of sill lengths.

Since the dams are released in succession, moving up-stream, if a faulty timing device fails to release a gate, and the other timers work successfully, one group of borders will be irrigated for longer than intended and one group will remain dry. Assuming the other timing devices do operate correctly, the system will resume normal functioning from there on and the effect of one fault is not cumulative. In contrast, if a release mechanism based on a sensor installed down the border-strip fails, that group of border-strips will continue to be irrigated. The result can be considerable run-off and lost irrigation opportunity time, which is particularly costly if water availability is limited. One way round this is to include within the sensor-based system a timer that operates as an over-ride – cutting in and dropping the gate if the irrigation goes on for more than a pre-set time.

An important part of the development of an automated border-strip system is fencing. It is best practice to fence off all head-races from the paddocks they serve, to enclose them in a long narrow race paddock. With appropriate planning, the head-race fencing layout can provide a lane system to simplify the movement of stock around a property. However, the primary benefit of fencing head-races is to enable regular close grazing of the head-races, separate from grazing the paddock itself. As a result, an even, steady flow of water to all areas supplied by the head-race is possible, and the timing of the irrigation of each group is regular. It also prevents stock damaging head-race sills and race berms.

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