What is Irrigation Efficiency?

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In New Zealand there has sometimes been a confusion of terms used in discussing irrigation efficiencies and irrigation water requirements. There is a real need for a common language to be used in submissions to regional water authorities, town and country planning appeal hearings, and environmental impact documents. The set of easily-understood definitions we propose here suits all irrigation methods. We hope that it will be discussed, perhaps improved, and either adopted or replaced by a better set.

Most confusion has arisen over the use of the terms **application efficiency** and **distribution pattern efficiency.** Although it is often the lowest of the four efficiencies defined, distribution pattern efficiency is not even mentioned in the New Zealand Standard (NZS 5103: *Code of practice for the design, installation and operation of sprinkler irrigation systems,* 1973).

The irrigator's intention is to supply water to fill or partly fill a crop root zone. Losses occur because of inefficiencies in all methods of extracting, reticulating and applying the water. This means that a greater quantity of water must be taken from the source than is actually required in the root zone. We can define a set of efficiencies which relates the input volume of water (in a given time period) to the output volume of water required to achieve a certain result.

The examples we shall give for surface, sprinkler and trickle irrigation show that the same kinds of losses occur in each case. So the set of efficiencies defined below is general to at least these three types of irrigation, and probably to other types. The definitions which follow use general terms which cover all the irrigation systems. 'Application devices', for example, are the sills of border dyke irrigation (Figure 1), the sprinklers of sprinkler irrigation (Figure 2), or the various kinds of emitters in trickle irrigation (Figure 3).

We obtain an efficiency by dividing the volume of water delivered to one point of the irrigation system by the volume which was present at an earlier point of the system. The resulting ratios may be multiplied by 100 to express them as percentages. Dealing in **volumes** of water implies a time period. This could be a day, an irrigation season, a year, or whatever the circumstances require. We can examine the kind and amount of the losses for each sort of efficiency (see Table 1).

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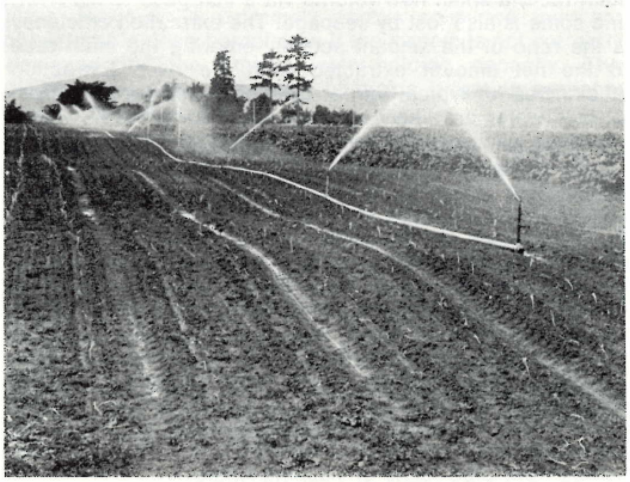

Sprinkler irrigation in the Wairarapa.

IRRIGATION EFFICIENCIES

Extraction efficiency (e_x) =

$$\frac{\text{volume delivered to the reticulation system}}{\text{volume extracted from the supply}}$$

Reticulation efficiency (e_r) =

$$\frac{\text{volume delivered to the application devices}}{\text{volume delivered to the reticulation system}}$$

Application efficiency (e_a) =

$$\frac{\text{volume delivered to the application surface}}{\text{volume delivered to the application devices}}$$

Distribution pattern efficiency (e_p) =

$$\frac{\text{volume delivered to the crop root zone}}{\text{volume delivered to the application surface}}$$

Irrigation system efficiency (e_i) =

$$\frac{\text{volume delivered to the crop root zone}}{\text{volume extracted from the supply}}$$

Table 1: LIKELY VALUES OF VOLUMETRIC IRRIGATION EFFICIENCIES

	Gravity border-dyke	Piped sprinkler	Trickle
Extraction efficiency e_x	80 - 100%	90 - 100%	90 - 100%
Reticulation efficiency e_r	60 - 90	95 - 100	95 - 100
Application efficiency e_a	90 - 100	70 - 100	90 - 100
Distribution pattern efficiency e_p	30 - 80	60 - 90	80 - 100

Note that in the table we have shown the ranges of efficiencies which we consider representative in irrigation practice at present. These are intended only as a check that values estimated in particular cases fall within the typical range for that irrigation application method. They are not intended for comparing application methods in general. **In particular, people must not take the mid-point of each range and come up with a magical number to compare, say, 'border-dyke' with 'sprinkler' irrigation.**

Extraction Efficiency (e_e)

Extraction is the removal of water from a source with the intention of supplying it to a reticulation system. Figure 1 shows a border-dyke irrigation scheme fed by gravity from a river. Although most of the water removed enters the main race, a small flow returns via a fish pass to the river, and some is also lost by seepage. The extraction efficiency is the ratio of the amount actually entering the main race to the net amount extracted from the river. Extraction efficiencies for typical border-dyke schemes supplied from surface water are likely to range from 80 to 100%.

Losses also occur in sprinkler irrigation systems (Figure 2). For instance, a pressure relief valve at the head of a well passes water to waste while a mainline hydrant is closed during sprayline shifting. Or if an open race is used to supply water for the pump intake, we may need a flow greater than the extraction rate to keep the intake covered. Leakage can also cause minor losses. Any water which is taken from the source but not delivered to the reticulation system becomes a loss and reduces the extraction efficiency from its maximum value of 100 percent. In practice, extraction efficiency for sprinkler systems should be high—say 90-100%.

For a well designed trickle irrigation system (Figure 3), extraction efficiency should be 90-100%. The only loss comes from pipe leaks or flushing filters.

Reticulation Efficiency (e_r)

In border-dyke irrigation, reticulation efficiency is lowered by seepage losses in the unlined head races and distributaries. Water overflows from the races and remains in the headrace after irrigation. Since this water does not reach the application devices, it is a loss. Another important loss is the 'waste' water or 'return flow' which goes back into the water source—although we might not regard this water as lost if it is diverted to some other use. These losses result in a 60-90% efficiency for border-dyke reticulation, but we may find much lower values. In a particular situation, we could separate **scheme** reticulation efficiency from **farm** reticulation efficiency by considering the losses separately.

In sprinkler irrigation systems, pipe leaks and sprayline draining can cause reticulation losses. But in properly maintained, piped reticulation systems, losses should be small, with a reticulation efficiency of 95-100%. The reticulation efficiency of trickle irrigation falls below 100% only through occasional failures such as leaks in the piping or the accidental removal of a whisker tube or emitter. It would probably lie between 95 and 100 percent.

Application Efficiency (e_a)

Once water has been delivered to the sills of a border-dyke irrigation system, it can be lost from the application surface by evaporation or by running right over the strips into a wipe-off (toe drain). We may get runoff if we apply enough water to supply the lower end of the strip adequately, or when automatic controls fail. Such losses should be reasonably small, and we can expect high application efficiencies of 90-100%.

Evaporation and wind drift prevent some of the water from sprinklers reaching the application surface. We get evaporation both from the spray and from the wetted foliage. Application efficiency for sprinklers is probably 70-100%.

The path of the water from trickle irrigation application devices to the wetted area does not usually lead to significant evaporation or wind losses. High values of application efficiency (90-100%) would be normal.

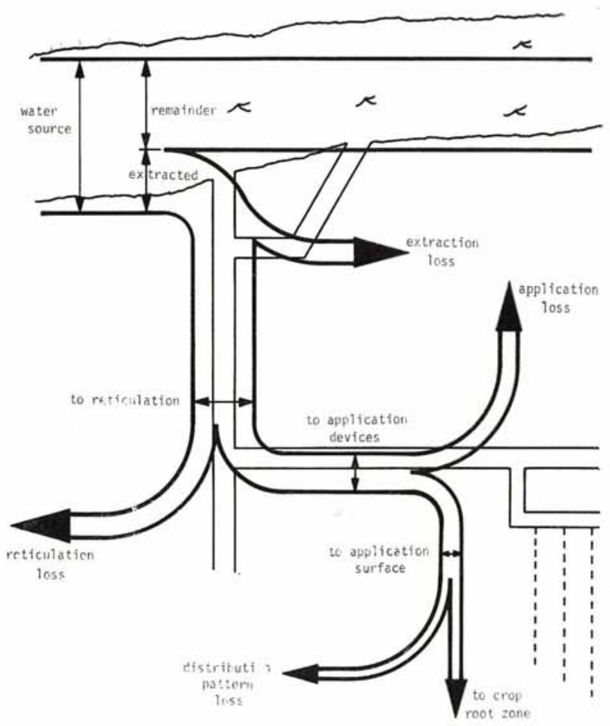

Figure 1: **Water delivered and lost in a border-dyke irrigation system.**

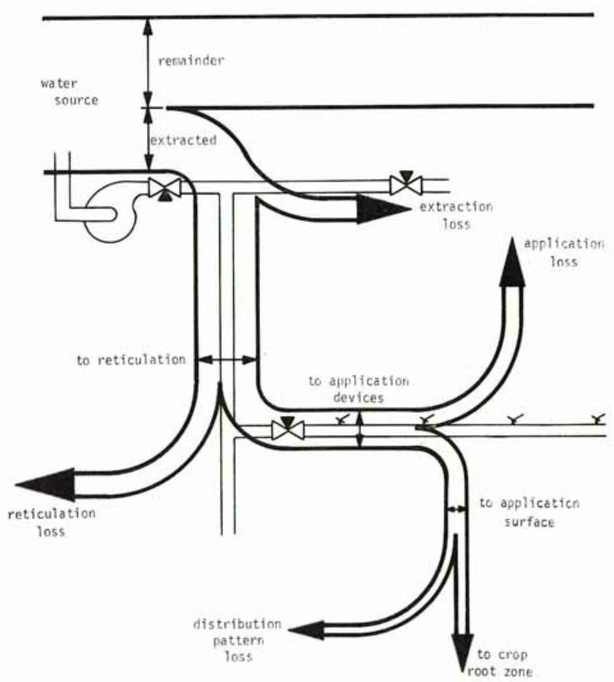

Figure 2: **Water delivered and lost in a sprinkler irrigation system.**

Distribution Pattern Efficiency (e_p)

Distribution pattern efficiency has often been entirely neglected, but it is an important factor in determining the efficiency of the overall system. Not only is it often the **lowest** of the four efficiencies defined, but it is closely linked to the uniformity with which water is distributed over the application surface. However, it should not be confused with the various 'coefficients of uniformity' used in irrigation, which are only measures of how evenly the water is distributed. Distribution pattern efficiency is a volumetric efficiency, like the others defined in this paper. If all of the water delivered to the application surface ended up in the crop root zone, distribution pattern efficiency would be 100 percent.

With border-dyke irrigation, it is well known that in some places a lot of water must seep past the root zone to make sure that a minimum specified amount will be delivered over the whole bordered strip. This situation is aggravated by very permeable soils, gradual slopes and small inflows. Actual efficiencies differ widely, with 30-80% being typical. However only a well-designed and well-managed system with an ideal combination of soil, slope, length and inflow rate would approach the upper values.

It is difficult to apply water uniformly with sprinkler systems operating in the windy conditions which prevail in New Zealand. More water than is actually required must be applied to be sure that most of the irrigated area receives the desired amount. Water is lost from the over-watered areas by deep percolation or surface runoff. As the importance of even ripening and frost protection has increased, so we have become more aware of the need both for uniform watering and for designs which provide an adequately watered area. Before the importance of uniformity was recognised, distribution pattern efficiencies for sprinkler irrigation were probably very low. A range of 60 to 90 percent should now cover most systems.

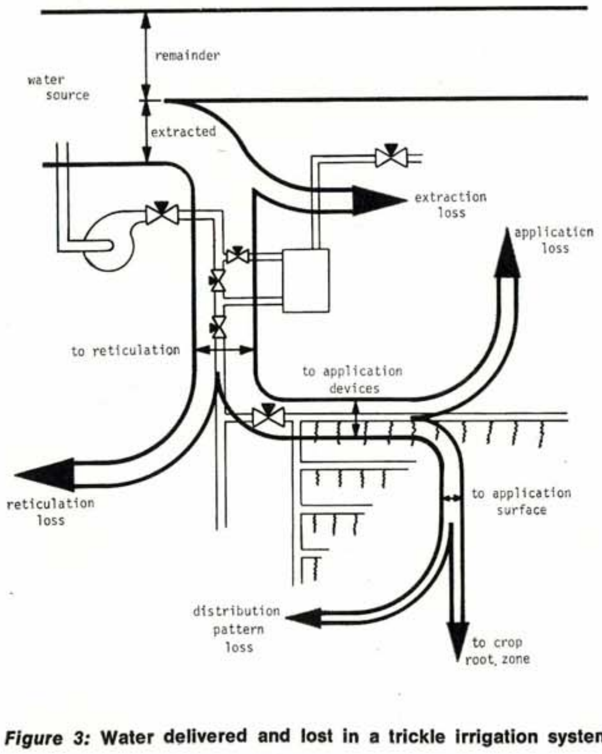

Figure 3: **Water delivered and lost in a trickle irrigation system.**

Trickle irrigation usually results in a crop root zone and application surface which are intimately related. The crop root zone might even have developed its size and shape in response to the applied water during the growth of the plant. However in extremely porous soils, we may get considerable deep percolation if the system is not correctly designed for the limited water-holding capacity. The distribution pattern efficiency of trickle irrigation probably ranges from 80 to 100%.

All values of distribution pattern efficiency depend for their accuracy on a reasonable choice of 'crop root zone'. In fact, it would be more logical to define distribution pattern efficiency in terms of the 'volume of water made available to the crop', but there is no direct way of establishing this volume. New Zealand Standard 5103 lists 'effective crop root depths', with notes on modifying the values for conditions other than 'unimpeded growth'. In the case of widely separated plants such as trickle irrigated trees, the crop root zone is a set of separate volumes around each plant. But in many other cases it consists of all soil under the application surface to the predetermined depth of most of the crop roots.

Irrigation System Efficiences (e_i)

Because the irrigation efficiencies chosen are a set of true volumetric efficiencies, they can be multiplied together to give the irrigation system efficiency:

$$e_i = \frac{e_x}{100} \times \frac{e_r}{100} \times \frac{e_a}{100} \times \frac{e_p}{100} \times 100\%$$

The irrigation system efficiency e_i expresses the percentage of the water extracted from an irrigation supply which actually ends up in the crop root zone.

Table 1 summarises the ranges of efficiencies chosen for the examples of border-dyke, sprinkler and trickle irrigation. We must emphasise that these ranges are estimates, based on our own experience and discussions with others interested in irrigation in New Zealand. Further experimental evidence will make it easier to select more precise values. The important task now is to understand—and if possible agree on—the meaning and use of efficiency terms for irrigation systems.

We can estimate the overall efficiency of a particular irrigation system by just combining the individual efficiency estimates. The efficiency of a trickle irrigation system is likely to fall between 60 and 100 percent. We believe 80-100% would be typical. Sprinkler and border-dyke systems give much wider ranges. Someone working out estimates of efficiencies for an on-farm sprinkler irrigation system could well get a result of 50-75%.

When we are dealing with border-dyke systems which are part of larger schemes, we must consider whether 'on-farm' or 'whole-scheme' volumetric efficiencies are relevant. The allotted period of time is also important, as there may be big variations during a season. A person who makes individual estimates of e_x, e_r, e_a and e_p for a border-dyke system extracting river water to feed a single farm should not be surprised with a resulting e_i of only 20-50%.

How much water is profitably used and how much is wasted are questions which must be considered in choosing irrigation water supply and application methods. Although other factors will often be left to those competent

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What is Irrigation Efficiency ?

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in irrigation design, the quantity of water an irrigation system will use may be a matter of general interest. The set of irrigation efficiencies proposed here allows everyone to talk the same language.

Other kinds of efficiencies have been proposed for use in the design and evaluation of irrigation systems. The set we have discussed relates only volumes of water used and volumes lost.

Even so, other terms have been adopted (particularly overseas) for the five efficiencies defined, or for combinations of them. We have not attempted to review these, as this would lead only to confusion. Instead we have chosen a reasonable set of efficiencies, pointed out what losses must be estimated in order to assign numerical values to them, and given likely ranges of variation.

There are clear benefits from agreeing on a set of definitions applicable to all irrigation systems. Here we have expanded considerably the limited discussion of efficiency contained in New Zealand Standard 5103. If such a set of definitions is adopted as standard terminology, New Zealand will be better off than other countries where irrigation is practised. ●

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