

LAND & WATER RESOURCES RESEARCH &
DEVELOPMENT CORPORATION

DETERMINING A FRAMEWORK, TERMS AND DEFINITIONS FOR WATER USE EFFICIENCY IN IRRIGATION

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Barrett Purcell & Associates Pty Ltd.
Consulting Water Resources and Irrigation Engineers
1 Bowen Street
NARRABRI NSW 2390
Ph: 02 67921265
Fax: 02 67924570
Email: bpa@mpx.com.au

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1. Executive Summary

1. Executive Summary

This report outlines the results of a consultancy to “Determine a Framework, Terms and Definitions for Water Use Efficiency in Irrigation”.

An issues paper was prepared in May, 1999 outlining the background, a simple framework, possible definitions for water use efficiency, examples of the most recent definitions of irrigation efficiencies and other issues considered relevant.

Fifty-six (56) individuals and organisations were identified as being representative of the major stakeholders in the national irrigation industry. Each of these was invited to a one day national workshop in Sydney on 10th June, 1999 and was supplied with the Issues Paper and a full list of workshop invitees.

Thirty-one (31) of the invitees participated in the workshop and agreement was reached on all issues by a clear majority.

The workshop agreed on the following.

Framework for Water Use Efficiency

A suitable framework for discussing Water Use Efficiency (WUE) is shown in Figure 2(a). This framework should cover all forms of irrigation enterprises and can also be applied to dryland cropping.

Terms and Definitions for Water Use Efficiency

The workshop concluded that the term “Water Use Efficiency” should be restricted to a generic label for any performance indicators used to study water use in crop production. This label, Water Use Efficiency, need not be defined but should be considered like a label on a tool box. Inside the tool box are many specific performance indicators that should be referred to as Water Use Indices. Any water use index (within this tool box) should be clearly defined with specific units when used.

The range of indices is almost limitless depending on the variables studied. Some indices will apply equally to both irrigated and dryland agriculture. A range of typical Water Use Indices are detailed in Section 5.3.

Irrigation Efficiency Definitions

The specific irrigation efficiencies selected for adoption by the Australian irrigation industry followed the Food and Agricultural Organisation of the United Nations – Irrigation and Drainage Paper 24 concepts with slight modifications to the wording as detailed in Table 2.

2. Background

2. Background

2.1 Project Initiation

2.1 PROJECT INITIATION

This consultancy was originated by the National Irrigation Efficiency Group (NIEG), a sub-committee of the National Program for Irrigation Research and Development (NPIRD) to initiate the development of irrigation efficiency standards throughout Australia. This is the first stage of a four stage project, with the four stages being:

1. Clarifying and standardising terms and definitions
2. Identifying and gaining agreement on appropriate indicators and measurements
3. Developing and gaining acceptance of measurement protocols
4. Developing suitable methods for data interpretation and presentation

The aim of each of the four stages is to have outcomes that are accepted nationally as the irrigation industry standards.

2.2 Stage One Objectives

2.2 STAGE ONE OBJECTIVES

The first objective of this consultancy was to determine and gain national acceptance of a framework for irrigation water use efficiency. The framework is to tie together all performance indicators related to irrigation management.

The next objective was to clarify and standardise the terms and definitions for irrigation water use efficiency that can be universally applied across the diverse Australian irrigation industry.

To ensure widespread adoption of these outcomes, representatives from as many of the major stakeholders in the irrigation industry as possible were invited to participate in the process and to work through the two objectives (see Appendix A).

3. The Issues Paper

3. The Issues Paper

The Issues Paper (Appendix B) provided a starting point for the workshop attendees. The paper briefly outlined the importance of consistent terms and definitions and introduced a simple framework for water use efficiency (Figure 1). Current terminology and definitions for irrigation efficiencies were also discussed based on the most recent work in this area. The definitions shown in Table 1 were utilised, not to exclude other work, but to highlight the most recently accepted definitions. Each workshop participant was supplied with an Issues Paper to provide background and project objectives.

4. National Workshop

4. National Workshop

Thirty-one people attended a national workshop in Sydney on 10th June, 1999. Fifty-six groups and individuals were invited to participate Australia-wide (see Appendix C). While not all invitees could participate a representative cross-section of stakeholders attended.

The workshop was split into two working groups of equal size running concurrently. Both groups worked through all the issues raised in the issues paper.

The initial task was to develop a framework. The rationale behind the framework developed in Figure 1 was explained. Once general agreement on Figure 1 was reached, the groups worked their way through the more complex framework shown in

Figure 2. This framework was developed to include all aspects of an irrigation system that affect irrigation water use efficiency. This version of Figure 2 includes modifications suggested at the workshop.

Development of this framework formed a foundation for moulding definitions of water use efficiencies and irrigation efficiencies. The groups worked through definitions for:

- > Water Use Efficiencies
- > Irrigation Field Application Efficiency
- > Distribution Efficiency
- > Conveyance Efficiency
- > Overall Project Efficiency

To ensure the results of the workshop were fully representative, a final plenary session was facilitated as one group to review results from each working group. Any differences between group views were worked through until agreement was reached by a clear majority. Fortunately there was good agreement between groups.

Table 1. Some Recent Definitions of Irrigation Efficiency

Term	FAO (1977)	ASCE (1973,1990)	Bos, <i>et.al.</i> (1993)	IAA (1998)
Overall Project Efficiency (E_p)	<u>Water made available to crop</u> Water released at headworks		<u>Crop Water Requirement</u> Total Inflow into Canal System	<u>Crop Water Use</u> Total Inflow into System Supply
Conveyance Efficiency (E_c)	Water received at inlet to block of fields Water released at headworks	<u>Water delivered to point of use</u> Water supplied to conveyance system	<u>Total Outflow from Canal</u> Total Inflow into Canal	Total <u>Outflow from Supply System</u> Total Inflow into Supply System
Distribution Efficiency (E_d)	Field canal efficiency: <u>Water received at field inlet</u> Water received at inlet of block of fields		<u>Field Level Delivery</u> Total Inflow into Canal System	Water <u>Delivered to Irrigation Field</u> Total Inflow into Supply System
Field Application Efficiency (E_a)	Water <u>directly available to crop</u> Water received at field inlet	Unit Irrigation Efficiency: Irrigation water required for <u>beneficial use in a specified area</u> Water delivered to this area	<u>Crop Water Requirement</u> Water Delivery to Field	<u>Crop Water Use</u> Water Delivered to Irrigation Field

Figure 1.

FIGURE 1.
Framework for Water Use Efficiency (Simple version)

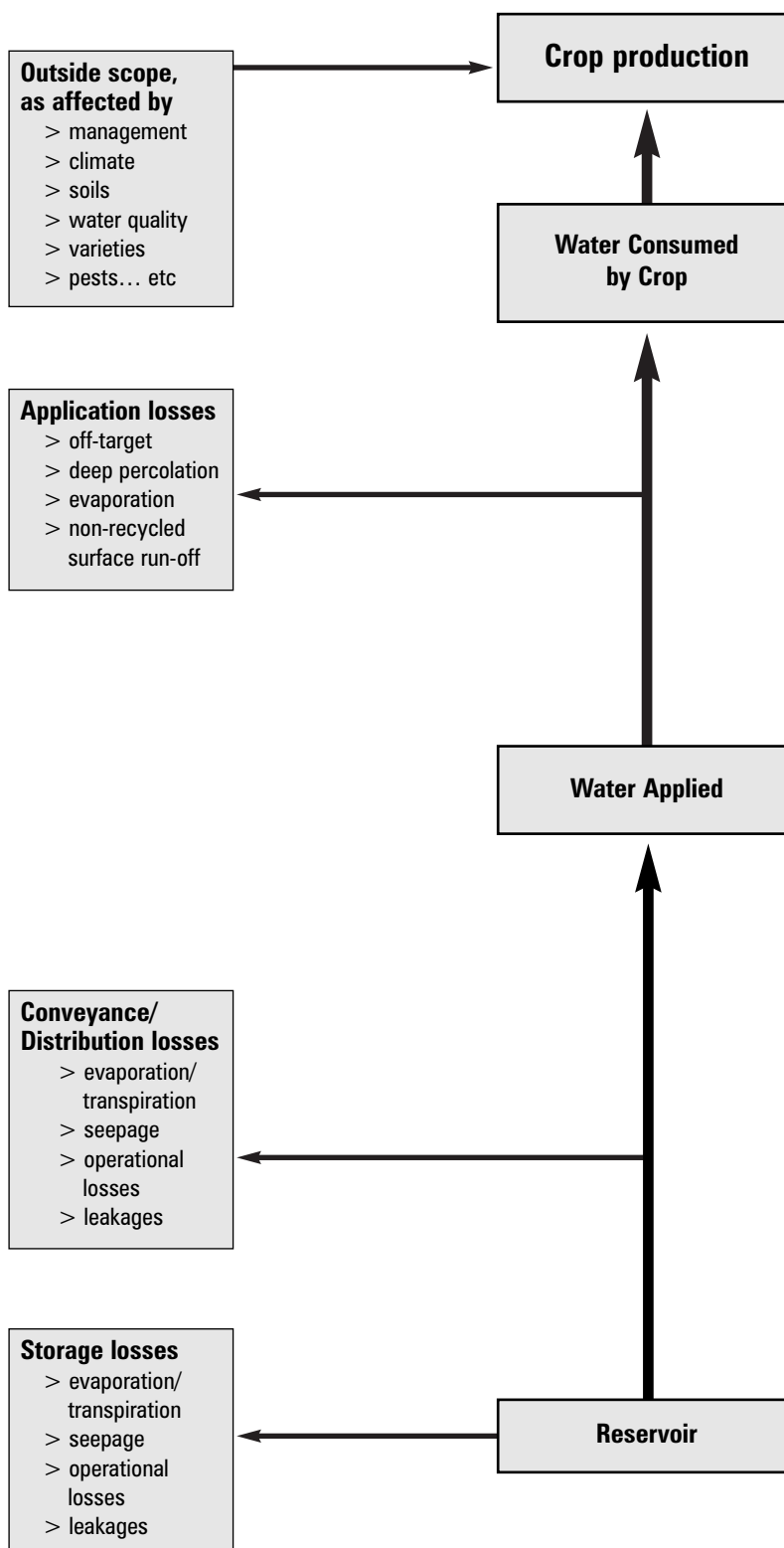
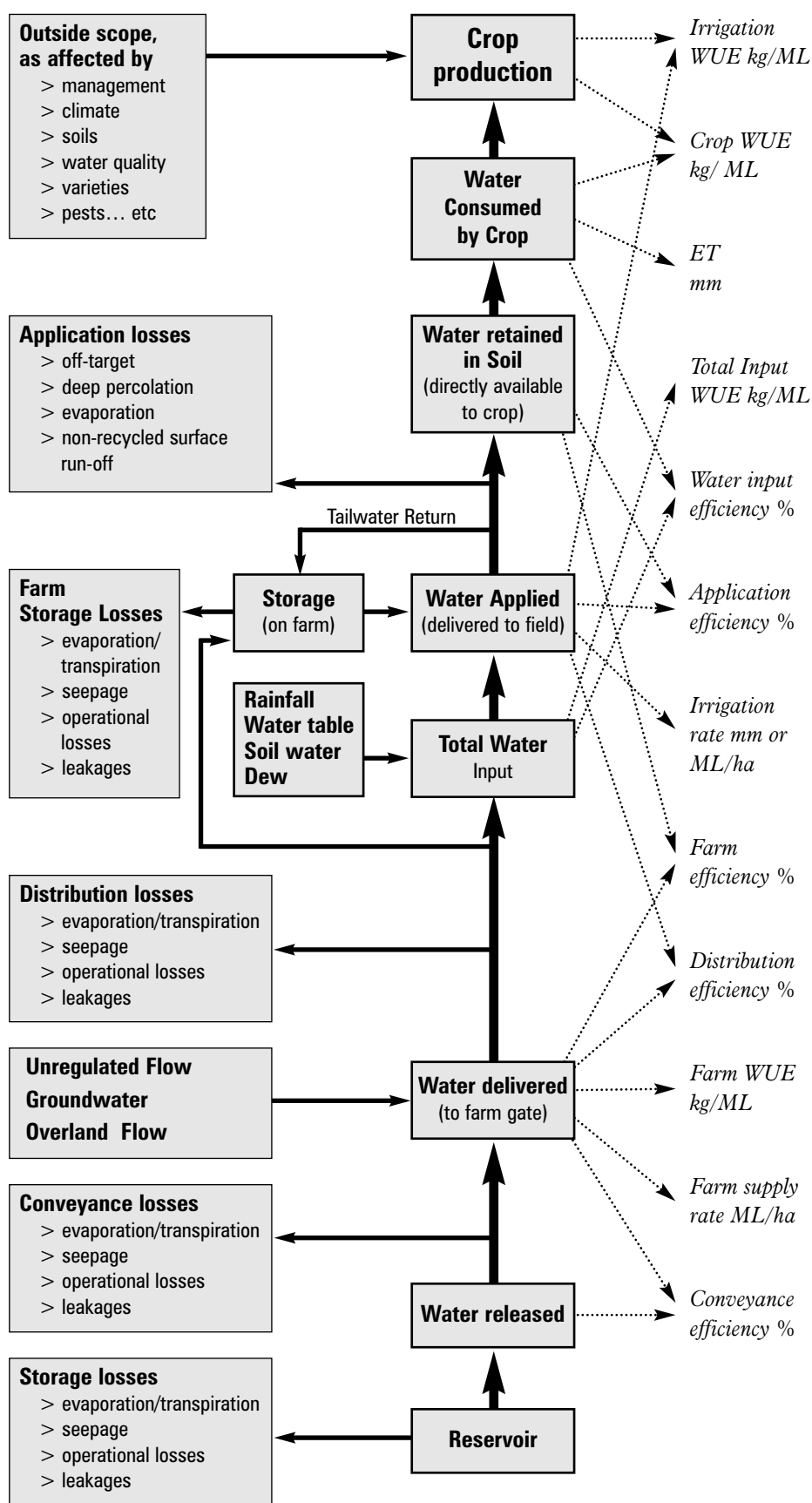


Figure 2.

FIGURE 2.
Framework for Water Use Efficiency (Comprehensive version)



5. Workshop Outcomes

5. Workshop Outcomes

The workshop gathered people from academic, government department, consulting, water supply organisation, and farming backgrounds. At the outset there was recognition of the need to balance science and rigour against what is measured and used by irrigators and water supply authorities in their normal activities. While there is scope to increase and improve what is currently measured there was agreement that at present the most likely data available would be:

- > volume of water delivered from the scheme headworks
- > some volume measurements at major sub-district offtakes
- > water volume delivered at the farm gate
- > water pumped at the river pumping station or at the farm bore or well
- > area of crop grown
- > crop yield (tonnes, bales, litres milked, etc.)
- > rainfall
- > some soil water measurement (irrigation scheduling)
- > some crop water use data from irrigation scheduling.

The first point of agreement at the workshop was that **regardless of any other outcome, all water use or irrigation efficiency terms when used should be defined clearly**. There are too many varying “accepted” definitions for these terms to assume that an audience will know which definition is being used.

5.1 Framework

5.1 FRAMEWORK

Again, when dealing with the framework for water use efficiency, it was agreed that there are many acceptable definitions and terms presently used depending on the purpose. It was also agreed that the number of definitions presently used and their relationship was complex.

It was decided to look at the framework by first looking at a generalised irrigation system as shown in Figure 1. This shows the simplest water cycle along with potential losses and its relationship to crop production.

To better understand the framework for common water use efficiency terms the more comprehensive Figure 2 was developed showing the same flow chart as Figure 1 but in an expanded form. This figure also shows the most commonly accepted water use efficiency terms, their derivation and relationships. It should be noted that there could be alternative definitions for some of these terms.

5.2 Efficiency versus Index

5.2 EFFICIENCY VERSUS INDEX

When dealing with the detailed definitions of the terms shown in Figure 2 there is a mixture of units, all referring to “efficiencies”. For example, irrigation water use efficiency is defined as:

$$\frac{\text{Total Crop Production (kg)}}{\text{Irrigation Water Applied (megalitres (ML))}}$$

However, to many, an efficiency is a dimensionless number, expressed as say 80% or 0.8. An example is conveyance efficiency, which is:

$$\frac{\text{Water Delivered to the Farm Gate (ML)}}{\text{Water Released from the Headworks (ML)}} \times 100 \%$$



Irrigated and dryland agriculture straddles many disciplines:

- > agronomy
- > engineering
- > economics
- > soil science
- > etc.

The present “definitions of WUE are confusing to some and do not fit all of the above disciplines. There needs to be compromise within each discipline to enable a set of universal WUE definitions to be accepted.

The first step in this process was agreement at the workshop that specific performance indicators should be referred to as indices, not efficiencies. (i.e. an irrigation water use efficiency would become an irrigation water use Index)

This would aid in reducing confusion and allow the use of dimensionally correct performance indicators.

There was acceptance that the term Water Use Efficiency was well known and widely used. It was also recognised that the change from “efficiency” to “index” may result in some resistance but to retain a term which was confusing would be worse.

5.3 Performance indicators

5.3 PERFORMANCE INDICATORS

When dealing with the many variables in the water use efficiency area it becomes necessary to define more and more performance indicators to serve the purpose at hand. This has been another reason for confusion with the water use efficiency terminology. Performance Indicators should not be restricted to those that fit the “efficiency” label.

The index approach adopted by workshop provides a more structured approach. A simple analogy would be to compare the performance indicators as a number of individual tools within a toolbox. The toolbox has the label “Water Use Efficiency” on the front and each tool (performance indicator) fits within this generic area.

This concept has the benefits of retaining the generic term that is familiar to the industry whilst being able to deal with specifics in a dimensionally correct manner without restricting the range of performance indicators available.

The performance indicators do not necessarily have to fit into the format of:

$$\frac{\text{Unit of Product.}}{\text{Unit of Water}}$$

Any performance indicator can be tailor made to suit the purpose of study. The index must, however, be clearly defined with units specified.

Some examples of performance indicators include:

> Gross Production Water Use Index =	$\frac{\text{Total Product (kg).}}{\text{Total Water Applied (ML)}}$
> Irrigation Water Use Index =	$\frac{\text{Total Product (kg).}}{\text{Irrigation Water Applied (ML)}}$



$$\begin{aligned}
 > \text{Marginal Irrigation Water Use Index} &= \frac{\text{Marginal Production due to Irrigation (kg).}}{\text{Irrigation Water Applied (ML)}} \\
 > \text{Crop Water Use Index} &= \frac{\text{Total Product (kg).}}{\text{Evapotranspiration (mm)}} \\
 > \text{Gross Production Economic Water Use Index} &= \frac{\text{Gross Production (\$).}}{\text{Total Water Applied (ML)}} \\
 > \text{Irrigation Economic Water Use Index} &= \frac{\text{Gross Production (\$).}}{\text{Irrigation Water Applied (ML)}} \\
 > \text{Marginal Irrigation Economic Water Use Index} &= \frac{\text{Marginal Production due to Irrigation (\$).}}{\text{Irrigation Water Applied (ML)}} \\
 \text{Crop Economic Water Use Index} &= \frac{\text{Gross Production (\$).}}{\text{Evapotranspiration (mm)}}
 \end{aligned}$$

etc.

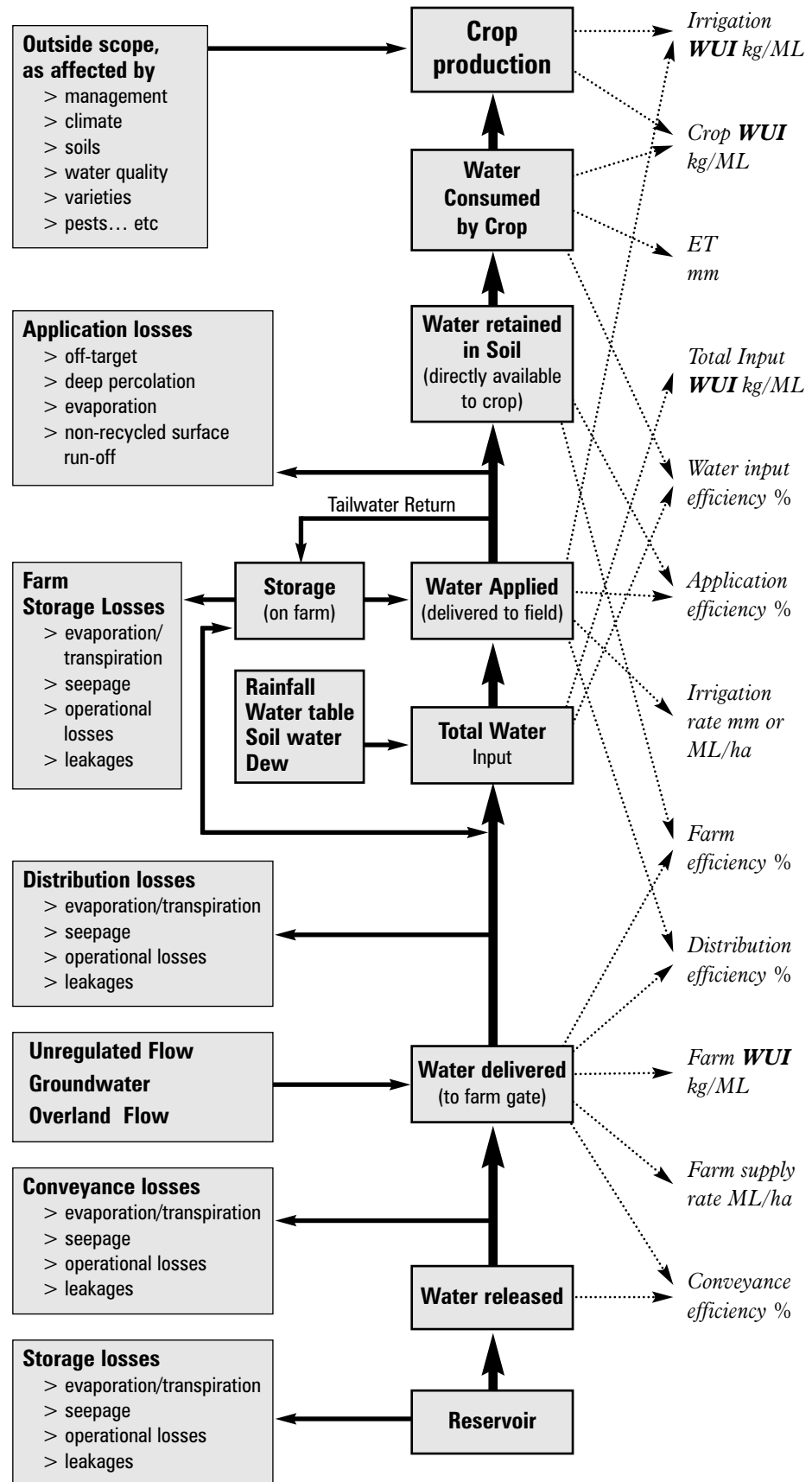
Note – All indices should be clearly defined with units specified

Figure 2(a) shows the same framework for water use efficiency as Figure 2 but with performance indicators expressed as indices. It was noted at the workshop that the index concept could also apply to dryland farming performance indicators.



Figure 2.a

FIGURE 2.a
FRAMEWORK FOR WATER USE EFFICIENCY (COMPREHENSIVE VERSION)
Using Performance Indicators as Indices



5.4 Irrigation Efficiency Definitions

5.4.1 Conveyance and Distribution Efficiency

5.4 IRRIGATION EFFICIENCY DEFINITIONS

The need for this aspect of the project was driven by the overabundance of available definitions for irrigation efficiency. The workshop began discussions with definitions from four of the more recent and accepted sources (Table 1).

5.4.1 CONVEYANCE AND DISTRIBUTION EFFICIENCY

The four sources shown in Table 1 have very similar definitions for conveyance and distribution efficiency. The terminology used by the IAA (1998) was considered the most appropriate for Australian conditions.

Two points were raised during the workshop about conveyance efficiency and distribution efficiency:

- (a) There could be confusion with where conveyance stops and distribution starts, and
- (b) There could be confusion between distribution efficiency of a channel and the uniformity of distribution of an irrigation system within a field.

It was resolved with point (a) that confusion should be avoided by clearly defining the starting and finishing points within the supply system when measuring the system efficiency.

The FAO (1977) or the IAA (1998) definitions in Table 1 both could be used to distinguish between conveyance and distribution but in any case a clear definition of which section of the supply system is being considered will solve any potential confusion.

Uniformity of distribution is another in-field performance indicator which describes how evenly irrigation water is made available to plants throughout a field. This performance indicator could be subject of another study in itself but briefly can be described as a Uniformity Coefficient (C_u), Christiansen (1942) or as a percentage, Kruse (1978).

A clear distinction must be made between canal distribution efficiency and uniformity of distribution of an irrigation event when either is used.

5.4.2 Field Application and Overall Project Efficiency

5.4.2 FIELD APPLICATION AND OVERALL PROJECT EFFICIENCY

The definitions of Field Application Efficiency and Overall Project Efficiency in Table 1 have significant differences and hence dominated discussions. The ASCE (1973, 1990) definition was considered too general to be of practical use. The Bos, *et.al.* (1993) definitions are based on crop water requirement which is calculated theoretically and susceptible to inconsistencies. While the IAA (1998) general terminology was considered good, it is based on crop water use which is difficult to measure accurately in the field.

There was strong support, therefore, for the FAO (1977) definitions. Water available to the crop can be measured from soil moisture contents in a laboratory or indirectly in the field from irrigation scheduling devices now commonly used.

There was discussion at the workshop about whether a leaching fraction should be considered part of the Field Application Efficiency. It was resolved that while leaching was a beneficial use of irrigation water, it should be considered as part of deep percolation losses thus reducing the application efficiency. That is, an irrigation enterprise that requires leaching of the soil will be less efficient than one that does not.



5.4.3 Recommended Efficiency Definitions

5.4.3 RECOMMENDED EFFICIENCY DEFINITIONS

The definitions recommended at the workshop are shown in Table 2. The terminology used has been altered slightly from the FAO version to better suit Australian conditions.

Table 2.

Table 2. Recommended Irrigation Efficiency Definitions

Term	Definition
Overall Project Efficiency (E_p)	$\frac{\text{Irrigation water available to crop}}{\text{Total inflow into supply system}}$
Conveyance Efficiency (E_c)	$\frac{\text{Total outflow from system supply}}{\text{Total inflow into supply system}}$
Distribution Efficiency (E_d)	$\frac{\text{Water received at field inlets}}{\text{Total outflow from supply system}}$
Field Application Efficiency (E_a)	$\frac{\text{Irrigation water available to crop}}{\text{Water received at field inlet}}$

These definitions allow a “nested” approach for a particular irrigation event (assuming no rainfall or unregulated flow into the supply system) as follows:

$$\text{Conveyance Efficiency} \times \text{Distribution Efficiency} \times \text{Field Application Efficiency} = \text{Overall Project Efficiency}$$

Finally, when dealing with either irrigation efficiencies or water use indices, spatial and temporal parameters need to be defined. For instance, a single irrigation application lasting less than one day on a single field will have different efficiencies and indices than full season irrigation over a large irrigation region. Seasonal performance indices can easily mask individual events and regional indices can mask individual elements.

Similarly, seasonal studies are more likely to be affected by rainfall, dew, subsoil, moisture and water tables.

6. Other Issues

6. Other Issues

6.1 Crop Water Use Efficiency

6.1 CROP WATER USE EFFICIENCY

Crop Water Use Efficiency, in particular, has a long standing history of use by agronomists defined as:

$$\frac{\text{Crop Production (kg)}}{\text{Evapotranspiration (mm)}}$$

The majority of workshop participants felt that this should change to a “Crop Water Use Index” to be consistent. It is recognised that there may be strong resistance to this change and it may take some time to achieve.



6.2 Field Application Efficiency with Localized Irrigation

6.2 FIELD APPLICATION EFFICIENCY WITH LOCALIZED IRRIGATION

The definition adopted for Field Application Efficiency in Table 2 is based on “irrigation water available to the crop.” The point was made at the workshop that the depth and area of the soil moisture reservoir may need to be defined to enable a fair comparison between system types. This would normally not be an issue but may be important for instance, when comparing bay irrigation to sub-surface drip irrigation of tree crops. Ideally a widely spaced tree crop should only require irrigation close to the tree. It is therefore possible that some of the irrigation water applied by bay irrigation may not be “available to the crop”.

The meeting agreed to keep the adopted definitions but noted that this concept should be considered when dealing with tree crops.

6.3 Focusing of Effort

6.3 FOCUSING OF EFFORT

Several workshop participants emphasised that any water use efficiency study of an irrigation region, district or enterprise needed to focus effort and expenditure on those areas which yield the biggest gains. This may require studies with variations of both time and area and the adopted definitions need to allow this flexibility.



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National Irrigation Efficiency Group Members:

- > Dr Nick Schofield
- > Dr Brian Hearn
- > Mr Tony Thomson
- > Mr John Wood
- > Mr Tony Meissner



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Appendix A

APPENDIX A

ATTENDEES LIST – National Workshop on Water Use Efficiency 10th June, 1999

Nick Austin – *NSW Agriculture, NSW*
 Ian Bell – *Department of Primary Industries and Fisheries, TAS*
 Matthew Bethune – *Institute for Sustainable Agriculture, VIC*
 Mike Bryant – *University of New England, NSW*
 Jeremy Cape – *Australian Irrigation Technology Centre (CSIRO), SA*
 Paul Dalton – *University of Southern Queensland, QLD*
 Noel Dawson – *Department of Natural Resources, QLD*
 Anthony Fairfull – *Barrett Purcell & Associates Pty Ltd. (Consulting Engineers), NSW*
 Dr Richard Faulkner – *University of New England, NSW*
 Peter Glennie – *Farmer, Moree NSW*
 Douglas Graham – *Murrumbidgee Irrigation, NSW*
 Brian Hearn – *National Irrigation Efficiency Group, Narrabri NSW*
 Bradley Hussey – *Bureau of Sugar Experiment Stations, QLD*
 Christina Jackson – *Australian Bureau of Statistics, ACT*
 Jo Lane – *Cotton Research & Development Corporation, NSW*
 Dr Basant Maheshwari – *University Of Western Sydney, NSW*
 Warren Mason – *Dairy Research & Development Corporation, VIC*
 Tony Meissner – *Department of Environmental Heritage & Aboriginal Affairs, SA*
 Dr Wayne S Meyer – *CSIRO Land & Water, SA*
 Derek Poulton – *Goulburn Murray Water, VIC*
 Jim Purcell – *Barrett Purcell & Associates Pty Ltd. (Consulting Engineers), NSW*
 Sandy Robinson – *Murray-Darling Basin Commission, ACT*
 Les Russell – *Department of Agriculture, Forestry & Fisheries, ACT*
 Nick Schofield – *Land & Water Resources Research & Development Corporation, ACT*
 Mark Skewes – *Primary Industries & Resources South Australia, SA*
 Alexander Szann – *Water Services Association Australia, NSW*
 Tony Thompson – *Primary Industries & Resources South Australia, SA*
 Sigrid Tijss – *IREC (CSIRO), NSW*
 Dr Rob Walker – *Grape Wine Research & Development Corporation, SA*
 John Wood – *Barracough & Co (Consultants), NSW*
 Don Yule – *Department of Natural Resources, QLD*



Appendix B

APPENDIX B

LAND & WATER RESOURCES RESEARCH &
DEVELOPMENT CORPORATION

ISSUES PAPER

DETERMINING A FRAMEWORK, TERMS AND DEFINITIONS FOR WATER USE EFFICIENCY IN IRRIGATION

Barrett Purcell & Associates Pty Ltd.

Consulting Water Resources and Irrigation Engineers

1 Bowen Street

NARRABRI NSW 2390

Ph: 02 67921265

Fax: 02 67924570

Email: bpa@mpx.com.au



1. Introduction

1. INTRODUCTION

“For the Australian irrigation industry to be competitive in the world marketplace, it must perform at a level equal to world’s best. Irrigation efficiency is a key measure of the effectiveness of irrigation management. High levels of irrigation efficiency translate into lower operating costs, improved production per megalitre of water used, and improved environmental management, all of which help to provide a competitive advantage.

Improvements in irrigation efficiency will be one of the benefits of the Land and Water Resources Research and Development Corporation National Benchmarking Project. The project’s priority is to establish a national benchmarking approach for irrigation systems and areas to evaluate and monitor performance of the systems in terms of the efficiency of water use” (Irrigation Association of Australia, 1998).

In order to evaluate and monitor systems and compare the performance of different systems and regions, it is first necessary to agree on how the evaluation and comparison is to be carried out. As a first step, agreement is required on the various definitions of irrigation water use efficiency.

2. Framework of terms

2. A FRAMEWORK OF TERMS

“Efficiency” is one of many performance indicators used to describe how well the process of irrigation is being carried out. Efficiency in the technical sense is a dimensionless number, being an output/input ratio, usually expressed as a percentage.

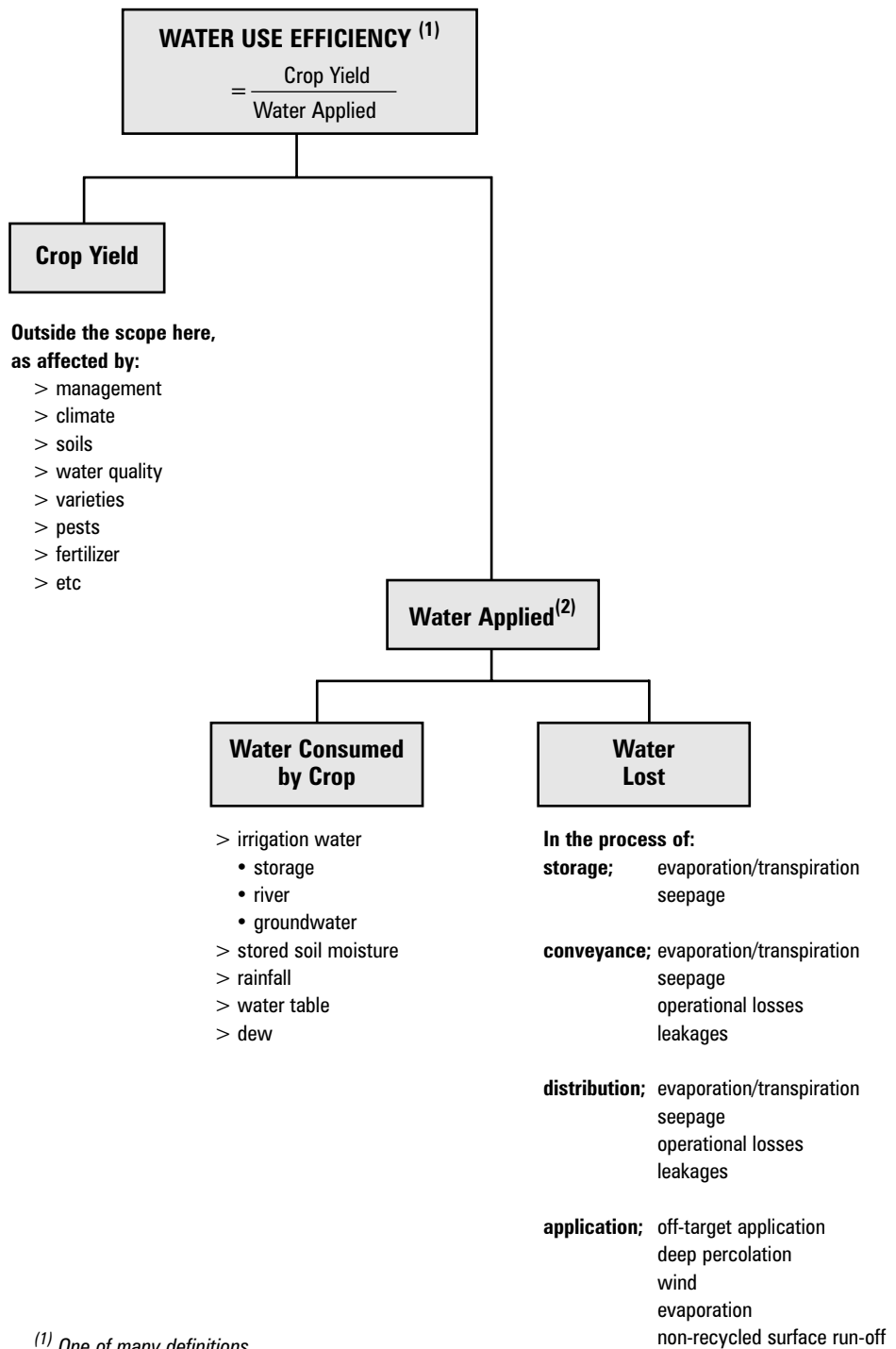
The expression “water use efficiency” (WUE) is widely and seemingly increasingly being used, sometimes as a performance indicator (e.g. mass of product per volume of water used) and sometimes as a generic term encompassing the various measures of irrigation efficiency. Although not strictly an “efficiency” (dimensionless) term, it is widely used as a performance indicator by farmers, agronomists, etc. Changing the term may be difficult and hence it shall continue to be used in this paper.

Water use efficiency is defined on Figure 1, with perhaps the most commonly used definition being

$$\text{WUE} = \frac{\text{Crop Yield.}}{\text{Water Applied}}$$

Figure 1.

FIGURE 1. A FRAMEWORK FOR WATER USE EFFICIENCY



⁽¹⁾ One of many definitions

⁽²⁾ Either on an event or seasonal basis

3. Defining water use efficiency

WUE can be increased by improving crop yields or reducing water applied. As shown on Figure 1, yields are influenced by many factors other than water and hence fall outside the scope of this paper. To reduce water applied, where water is lost and how much is lost needs to be identified. Hence a clear definition of the various measures of irrigation (“engineering”) efficiency is required.

3. DEFINING WATER USE EFFICIENCY

Hearn (1997) has outlined a number of definitions of water use efficiency, as follows.

Physiological WUE: The ratio between the rates of gas exchange (CO_2 entering as raw material for photosynthesis and water vapour leaving in the process of transpiration) between the atmosphere and leaves over a short time span (minutes).

Crop WUE: Yield divided by evapotranspiration.

Farm WUE: Total production divided by all water delivered to the farm gate plus rainfall.

Gross Production WUE: Total production of a farm or in a region divided by all water delivered to the farm gate(s).

Marginal Production WUE: Total production less production attributed to rainfall divided by all water delivered to the farm gate.

All of these definitions (and possibly others) have their place. Considerable discussion shall be required to determine the most appropriate for benchmarking irrigation performance.

One of the biggest difficulties shall be in determining the contribution to water consumed from various sources (see Figure 1). For example, considerable difficulty is encountered in allowing for (effective) rainfall. Also, high water tables may contribute to consumed water in some parts of a region, but not another. Water lost (not consumed by the crop) has to be accounted for. These losses are usually encompassed within the irrigation efficiency terms. A considerable amount of work is currently being carried out throughout Australia to determine irrigation efficiencies.

4. Defining irrigation efficiency

4. DEFINING IRRIGATION EFFICIENCY

In reviewing the literature it would appear that there are four basic terms to be defined when discussing irrigation efficiency:

- > Overall Project Efficiency (E_p)
- > Conveyance Efficiency (E_c)
- > Distribution Efficiency (E_d)
- > Field Application Efficiency (E_a).

Definitions of irrigation efficiency date back at least to the 1940’s and probably earlier. The difficulty of establishing a unique definition for each term that is universally acceptable has led to a plethora of definitions. Willardson (1972, quoted in Walker and Skogerboe, 1987) stated that at least 20 definitions of irrigation efficiency existed, with probably more added subsequently.

In attempting to rationalise the definitions, we have tended to stay with the main players and international precedents. Considerable work has already been undertaken in this field and this has been taken as the starting point. Generating new definitions, while perhaps a praiseworthy ambition, would be likely to prolong the dialogue and slow acceptance. All angles would appear to have been considered in the past and the task now is to sort through the alternatives to adopt or modify definitions as required.

The more recent work has tended to integrate past work and hence more recent definitions are offered for consideration. These are summarised in Table 1 and include the work of the Irrigation Association of Australia, which recently sought to determine a set of definitions for its adoption. Other authors not referred to in Table 1 are not excluded. Their contributions are added to the discussion which follows as required.

In reviewing the range of definitions for the four terms included in Table 1, it is apparent that there is reasonable agreement on some definitions but less on others.

Perhaps the most difficult and fundamental term to define shall be Field Application Efficiency. For this term, all definitions shown in Table 1 have essentially the same denominator, reducing the problem to one of selecting an appropriate numerator. Numerators tend to range from water required to water available to water used.

Table 1. SOME RECENT DEFINITIONS OF IRRIGATION EFFICIENCY

Term	FAO (1977)	ASCE (1973,1990)	Bos, <i>et.al.</i> (1993)	IAA (1998)
Overall Project Efficiency (E_p)	<u>Water made available to crop</u> Water released at headworks		<u>Crop Water Requirement</u> Total Inflow into Canal System	<u>Crop Water Use</u> Total Inflow into System Supply
Conveyance Efficiency (E_c)	Water received <u>at inlet to block of fields</u> Water released at headworks	<u>Water delivered to point of use</u> Water supplied to conveyance system	<u>Total Outflow from Canal</u> Total Inflow into Canal	Total <u>Outflow from Supply System</u> Total Inflow into Supply System
Distribution Efficiency (E_d)	Field canal efficiency: <u>Water received at field inlet</u> Water received at inlet of block of fields		<u>Field Level Delivery</u> Total Inflow into Canal System	Water <u>Delivered to Irrigation Field</u> Total Inflow into Supply System
Field Application Efficiency (E_a)	Water <u>directly available to crop</u> Water received at field inlet	Unit Irrigation Efficiency: Irrigation water required for <u>beneficial use in a specified area</u> Water delivered to this area	<u>Crop Water Requirement</u> Water Delivery to Field	<u>Crop Water Use</u> Water Delivered to Irrigation Field

“Water required” (evapotranspiration) may be most appropriate in determining proposed flow rates for the design of a new irrigation system, but is not necessarily the most appropriate numerator for monitoring existing systems. In the latter case, the numerator should reflect the irrigation water used, not necessarily total water use by the crop (which may receive contributions from stored soil moisture or rainfall, for example). Some definitions (eg. that proposed by the IAA) could lead to efficiencies in excess of 100 per cent. Burt (1995) takes this into account when he defines Irrigation Efficiency as

$$\frac{\text{Irrigation water beneficially used}}{\text{Irrigation water applied}}$$

This may lead to two definitions of field application efficiency, one for the predictive case (design of new systems) and one for the actual case (monitoring existing systems). Note also that Burt includes the leaching fraction in irrigation water beneficially used.

The range of definitions for both Conveyance Efficiency and Distribution Efficiency show a reasonable degree of consistency. An exception is the FAO definition, which distinguishes between the (conveyance) efficiency up to a block of fields (e.g. a farm, in the Australian context) and the (field canal) efficiency within the block (farm). This allows $E_p = E_a \cdot E_d \cdot E_c$.

While this approach has a certain mathematical elegance, caution is required in adopting definitions of international agencies as most have been proposed for less developed countries, generally for open channel systems, and not all are necessarily appropriate to Australian conditions. It may be better for E_d to be a measure of losses in the total distribution system, up to but not including the field. E_c could then be an alternative measure of losses in conveyance and could refer to any part of the conveyance system, e.g. the main supply canal, and would be a subset of E_d . Then $E_p = E_a \cdot E_d$.

Overall Project Efficiency is therefore satisfactorily defined, provided the earlier definitions are agreed upon. Note that as two definitions of E_a may be required, then two definitions of E_p may also be required. Hopefully these can be defined by context or by a subscript (proposed, actual) rather than by developing new terms.

For completeness, the term “On-farm Storage Efficiency” (E_s) should probably be added, as on-farm storage is an increasingly important component of some irrigation layouts.

$$E_s = \frac{\text{Water taken from on-farm storage}}{\text{Water delivered to on-farm storage}}$$

This term can be factored into Overall Project Efficiency as required.

All of the above terms can be applied to any type of irrigation system (eg. drip, sprinkler or surface) supplied from any water source with water distributed by any means (pipe, natural watercourse, open channel, etc.)

5. Other terms

5. OTHER TERMS

Note that there are, in some cases, quite different definitions for the terms used above. For example, Kovda *et.al.* (1973) use the term “water distribution efficiency” for a measure of the uniformity of application. Uniformity is an important measure of the

effectiveness of irrigation. Although falling outside the scope of this brief, it will subsequently require defining in a way that suits all irrigation systems as it is an essential in-field irrigation system performance indicator. Irrigation water may be applied with a high degree of efficiency but, with poor uniformity, large areas of the crop could be dead. Defining uniformity as an “efficiency”, however, tends to be confusing.

Numerous other terms are used under the guise of “efficiency”. The term “biological efficiency” is sometimes used and relates yield to the volume of water consumed by (or applied to) the crop. The term is therefore synonymous with one of the definitions of water use efficiency. The term “economic efficiency” is sometimes used to relate the value of product to the amount of water used. Other performance indicators may measure, for example:

- > tonnes per hectare
- > gross return (\$) per megalitre supplied
- > cost of water per tonne of product
- > gross return (\$) per cost of drainage (\$), etc.

None of these indicators are considered here, where the discussion is confined to appropriate definitions of the various water use efficiency terms.

6. Issues

6. ISSUES

Numerous issues arise from the above discussion, including the following:

- > The relationship between the definitions and benchmarking. Do we get the definitions conceptually correct or must the terms be measurable?
- > Should the discussion be extended further to include other performance indicators?
- > How should deliberate under-irrigation (to take advantage of possible rainfall) be compared to irrigation which fills the soil profile?
- > How should rainfall be handled generally in the definitions?
- > Should additional water for deliberate leaching be considered as “irrigation water beneficially applied” in the definitions?
- > How should tailwater recycling on farm or within a district be incorporated within the definitions?
- > How can irrigation efficiency be measured when water is supplied to a field from a variety of sources (river water, bores, harvested rainwater, etc)?
- > Should irrigation water be considered lost in terms of irrigation efficiency if in fact it is conserved in fallow for use by a subsequent crop?
- > Are the definitions equally suitable for each irrigation event and for seasonal efficiency?



Appendix C

APPENDIX C

Workshop Invitees

- > *Land and Water Resources Research and Development Corporation (LWRRDC) (2)*
- > *National Irrigation Efficiency Group (4)*
- > *National Irrigation Efficiency Group Reference Panel (9)*
- > *National Irrigation Science Network*
- > *Murray Darling Basin Commission (MDBC)*
- > *Australian National Committee of Irrigation and Drainage (ANCID)*
- > *Water Services Association of Australia*
- > *Australian Irrigation Council*
- > *University of Southern Queensland*
- > *University of Melbourne*
- > *Institute of Sustainable Agriculture Tatura*
- > *Water Policy Research Unit, University of New England (2)*
- > *Goulburn-Murray Water Authority*
- > *Murray Irrigation Limited*
- > *Department of Natural Resources (DNR) Qld*
- > *Department of Land and Water Conservation (DLWC) NSW*
- > *Department of Natural Resources & Environment VIC*
- > *Primary Industries and Resources SA*

OR

- > *Department of Environmental Heritage and Aboriginal Affairs SA*
- > *Water and Rivers Commission WA*
- > *Department of Lands Planning and Environment NT (Natural Resources Division)*
- > *Department of Primary Industries and Fisheries TAS*
- > *CSIRO Land and Water*
- > *Department of Agriculture, Fisheries and Forestry Australia*
- > *Irrigation Association of Australia (IAA)*
- > *Farming Systems Department, University of Western Sydney*
- > *ACTEW Canberra*
- > *Australian Irrigation Technology Centre*
- > *NSW Agriculture Unit on Irrigation Efficiency*
- > *Murrumbidgee Irrigation Corporation*
- > *Jemalong Irrigation*
- > *South West Irrigation*
- > *Sunraysia Rural Water Authority*
- > *Western Murray Irrigation Limited*
- > *Ord Irrigation Area*

Industry Representatives to be nominated by:

- > *Ricegrowers Association of Australia*
- > *Dairy Research and Development Corporation*
- > *Grape Wine Research and Development Corporation (GWRDC)*
- > *Cotton Research and Development Corporation*
- > *Horticulture Research and Development Corporation*
- > *Bureau of Sugar Experiment Stations (2)*
- > *Peter Glennie (Farmer – North West NSW)*

