3 Seasonal Irrigation Efficiency

Contents

3.1.1 Indicators

Schedule 3 outlines procedures for estimating measures of seasonal irrigation efficiency (SIE). A wide range of efficiency measures may be used, depending on scale, time-frame and issues under consideration. Commonly used indicators include irrigation efficiency, irrigation adequacy and drainage.

Those selected below relate to estimates of efficiency across an irrigated growing season or year. They provide information relating to economic or environmental implications of in-efficient irrigation systems or management. The indicators are calculated using soil moisture budgets; tracing inputs and outputs from a conceptual reservoir of some set size.

The schedule identifies varying levels of analysis ranging from very simplistic to highly detailed. The simplest is a quick estimate of Seasonal Irrigation Efficiency based on comparing total seasonal irrigation and rainfall with total estimated seasonal evapo-transpiration. A more detailed process is recommended where information is available. Therefore the schedule outlines a process for more detailed analysis, requiring knowledge of soil water properties, seasonal weather, potential crop water use, and irrigation system performance and management.

The quality of results from such exercises is dependent on input data, the quality of which should be recorded.

3.1.1.1 Seasonal application efficiency

Seasonal Irrigation Efficiency (SIE) is an estimate, calculated for a whole season or full year, of how much irrigation water that is applied is likely to have been used beneficially.

Beneficial uses include meeting evapo-transpiration requirements, frost protection and salinity management. In this New Zealand Code, the prime consideration is crop evapo-transpiration need, and uses for frost protection are considered separately.

The key indicator calculated is seasonal application efficiency (SAE), the ratio of crop water use to applied irrigation, net of changes in soil moisture storage.

3.1.1.2 Seasonal irrigation adequacy

Irrigation Adequacy is an estimate of whether sufficient irrigation is applied to meet the needs of a given proportion of the field. A commonly used indicator is low-quarter adequacy, which takes the average low-quarter applied depth as the scheduling criterion (Burt et al, 1997) and typically considers a single irrigation event.

Potential soil moisture deficit (PSMD) is used as the seasonal equivalent indicator, because summing individual-event irrigation adequacy results over the course of a season gives a false indication of adequacy.

Deep percolation resulting from irrigation (SDP_i), which is in effect application in-efficiency, is a key environmental indicator describing the amount of water that is lost to groundwater through non-uniformity or improper scheduling.

3.1.1.3 Other efficiency indicators

Drought induced yield loss (YL_{di}) and energy and water costs related to over-watering describe the financial implications of irrigation in-efficiencies.

3.1.2 Sources of information

Determination of irrigation efficiency indicators requires knowledge of beneficial water use, total water inputs and the soil's 'reservoir' capacity.

Typically seasonal irrigation efficiency will be calculated on the basis of the last complete season, using records of actual irrigation volumes, calculated estimates of water need, and knowledge of soil moisture storage at the beginning and end of the season.

The source of data used, and assessments of their reliability, should be recorded.

3.1.2.1 Water use

Because the key drivers of water use (PET) vary little within a district, water use by a given crop can usually be determined from district weather records and crop factors.

If on-site crop monitoring records allow, actual measured water use data should be used.

3.1.2.2 Water inputs

Water inputs require knowledge of irrigation quantities and rainfall, both adjusted to equivalent water depths. Irrigation is obviously field-specific. Because rainfall is so variable, information should relate to that received on-site.

3.1.2.3 Soil water holding capacity

Unless on-site data is known (e.g. from moisture monitoring records) soil water holding capacity (WHC) and readily available water (RAW) must be estimated.

Standard data for soils and crops in question may be available from published sources. On-site textural analysis may provide a reasonable estimate of WHC.

Plant rooting depth should be determined on-site. Text book values are widely variable and unreliable.

3.1.3 Determination of input data

3.1.3.1 Accuracy of input data and results

Many of the inputs can be entered with considerable precision, but are of limited or unknown accuracy. Therefore output results are of limited or unknown accuracy. Levels of confidence will be difficult to ascertain, but the precision of generated results should not be taken to imply a level of accuracy.

3.1.3.2 Soil moisture characteristics

The water holding potential of the soil should be calculated from the estimated soil WHC and the plant rooting depth. It is convenient to express water holding as a depth (mm).

The readily available water is estimated from WHC and some crop factor, typically management allowed depletion (MAD) or critical deficit (usually also a percentage).

For annual or new crops, root depth will increase with plant growth, so WHC and RAW will typically change over the season.

3.1.3.3 Estimating crop water requirement

Crop water requirement is dependent on climatic conditions, crop characteristics and plant available soil moisture. In a simple estimate, only the climatic and crop factors are considered.

Reference potential evapo-transpiration values (PET) should be obtained on-site or from relevant local climate station values. PET is then adjusted to account for crop specific water use factors (K_{crop}) and the ground cover fraction ($K_{ground\ cover}$). These may be combined into a single factor (K_c) the crop water use co-efficient.

The crop water requirement calculated is described as crop-adjusted evapo-transpiration (ET_{crop}) using Eqn 1.

In most cases it is satisfactory to assume plant water use stops when Critical Deficit (maximum allowable deficit, MAD) is reached. For very detailed analyses, some reduced rate of consumption should be allowed in calculating soil moisture balances.

3.1.3.4 System performance (DU_{lq})

No irrigation system applies water perfectly evenly, so under a full irrigation regime, some areas will receive more water than required while others do not receive enough.

In calculating many indicators, it is helpful to consider distribution uniformity. For example, the volume of water required to adequately meet the needs of most (7/8ths) of the crop is determined by adjusting the theoretical water requirement by the low quarter distribution uniformity coefficient (DU_{lq}).

The DU_{lq} is a key output from the system evaluations described in Schedules 4.1 through 4.7.

3.1.3.5 Root area wetted

Drip and micro sprinkler irrigation efficiency needs particular consideration, because only a fraction of the total soil area is actually watered.

Calculations must account for reduced soil reservoir capacity. This may be done by adjusting the effective AWC and RAW proportionally, or considering the zones separately.

3.1.3.6 Beneficial water requirements

Additional water may be required for particular purposes other than replacing ET. Alternative beneficial uses include frost protection, any leaching requirement, and pre-plant irrigations for weed germination or other reasons.

Such water use should be accounted for in determining irrigation efficiency. If water applied (e.g. for frost protection or soil conditioning) is retained and available for later plant use it should be included in calculations as irrigation.

If water applied for frost protection or soil conditioning drains (or causes other irrigation to drain) from the profile, it should be omitted from irrigation efficiency calculations, but may be included in a seasonal water use efficiency estimate (SWUE). This may include excess water applied to manage salinity (leaching), although this is rare in New Zealand.

3.1.3.7 Crop value

Financial losses can be estimated if potential yield and price are known, and a suitable drought response factor is available.

For field crops, in lieu of better data, a drought response factor, F_{dr} of 0.1% of potential yield per mm potential soil moisture deficit can be used for C4 plants (maize and sweetcorn) and a value of 0.2% /mm PSMD for other field crops.

3.1.4 Analysis detail

Decisions must be made about which factors to include and the detail with which soil moisture budgets and other calculations will be undertaken. Variables include climatic, crop and soil variables, and the irrigation system and its management.

The level of detail possible depends in part on the availability of reliable input information and in part on the purpose for which the analysis is being undertaken. The division of time periods and spatial zones for analyses also have significant effects on the results generated.

3.1.4.1 Time period

The size or number of time-steps considered influences results generated. The greater the division of any time period (the finer the time-steps) the more closely estimates can reflect reality. Wider time-steps integrate more events; summing rainfall, irrigation, ET and deep percolation. This typically underestimates certain factors such as the degree of drought and drainage.

If reliable information is available, a more detailed assessment will provide better information for future decision making. Weekly or daily weather and irrigation records provide a good or very good level of information.

3.1.4.2 Spatial variation

Analyses can be based on average values for variables such as applied depth. However, inclusion of distribution uniformity factors in calculations further increases the quality of analysis.

Typically three ‘virtual spaces’ can be considered: the area that receives the mean depth of application, and those receiving the low quarter and high quarter mean depths. Use weighted results when recombining data, using Eqn 26.

In drip or micro irrigation systems, where only part of the area is wetted, soil moisture trends in the irrigated and un-irrigated zones should also be considered separately.

Constructing independent soil moisture budgets for each area identifies where drought and drainage are occurring more accurately. The calculated indicator values can then be combined to give a value for the system as a whole.

3.1.4.3 Simple analyses

The most simple analysis uses total seasonal values to estimate an approximate efficiency. This level of analysis can be a useful starting point, easily calculated by hand or with a simple calculator.

Soil moisture storage capacity is not considered, except as change in status between the start and end of the season. Neither is consideration given to the timing of irrigation or rain, or the relationship of these events to water use (ET) in any particular time period. While this estimate can identify major problems, it does not provide the detail needed to make recommendations for improving system management.

Considerable experience in New Zealand, Australia and the United States shows that many irrigators do not have sufficient system performance knowledge, or maintain sufficient records, to allow even rough estimates to be made.

3.1.4.4 Detailed analysis

More detailed analyses involve soil moisture budgets with calculations based on periodic time steps. The desirability of computer programs to perform the calculations increases with the number of periods and detail of calculations. This level of analysis does permit increasingly accurate establishment of overall irrigation efficiency. It can be used to highlight ways in which system management, particularly scheduling and application quantities, can be adjusted to increase efficiency.

Data inputs include weather, soil moisture storage properties, crops and crop coefficients, irrigation events and system performance (distribution uniformity).

Estimates of performance rely on historic weather and management data. The quality of records of rainfall, PET and past irrigation practices determines the accuracy with which more detailed analyses of irrigation efficiency can proceed.

3.1.5 Efficiency calculations

3.1.5.1 Seasonal application efficiency

Seasonal application efficiency (SAE) is given by the ratio of water retained in the root zone to water applied to the field, over a full irrigation season or year (Eqn 8).

In more detailed calculations, the amount of water retained from each irrigation event should be summed to determine a seasonal result.

For greater accuracy, soil moisture balance calculations may be completed in each of three conceptual irrigated zones: the zone receiving the average application depth, and those receiving the average low quarter and high quarter depths.

The overall SAE is a weighted average of these calculated values, calculated according to Eqn 9.

3.1.5.2 Event Irrigation adequacy

Irrigation adequacy typically applies to an individual irrigation event. It measures the degree to which the soil moisture in some proportion of the field is restored to a level that meets or exceeds target soil water content.

A simple determinant is low quarter irrigation adequacy, IA_{lq} which is the ratio of the mean low quarter depth applied to the mean target depth required across the field as a whole (Eqn 10).

This assumes it is reasonable to adequately irrigate 7/8^{ths} of a field, leaving 1/8th under irrigated. IA_{lq} can be used to determine 'correct' irrigation scheduling:

IA_{lq}	< 1.0	under-irrigation
IA_{lq}	= 1.0	target irrigation
IA_{lq}	> 1.0	over-irrigation

3.1.5.3 Seasonal irrigation adequacy

If the adequacy of irrigation is summed over the course of a season, over- and under-irrigations may cancel out. This will give a false indication of adequacy, and fails to provide useful information for decision making.

For a seasonally relevant value of irrigation adequacy, potential soil moisture deficit (PSMD) gives a better indication of adequacy (lack of moisture stress). The equivalent indicator is therefore the low quarter potential soil moisture deficit ($PSMD_{lq}$). Alternatively, a PSMD for the field as a whole may be presented based on low, mean and high quarter estimates.

Seasonal deep percolation resulting from irrigation (SDP_i) is a measure of the amount of irrigation water applied that drains from the soil profile. It is therefore the equivalent indicator for excess irrigation over a season.

3.1.5.4 Potential soil moisture deficit

Potential soil moisture deficit (PSMD) is a measure of moisture stress experienced by a crop, and is correlated with yield loss.

PSMD is calculated using Eqn 3

3.1.5.5 Seasonal potential soil moisture deficit

Seasonal PSMD is calculated from soil moisture budgets by summing all deficits greater than the critical deficit (or MAD) using Eqn 12. Seasonal PSMD assumes any rain or irrigation is immediately available to plants, so is not the same as an aggregation of period SMD's.

To correspond to low quarter irrigation adequacy, a budget would be calculated using data for the low quarter zone. A potential soil moisture deficit in the low quarter zone ($PSMD_{lq}$) > 0.0mm equates to a seasonal irrigation adequacy (SIA_{lq}) < 1.0, as plants have experienced stress conditions.

To determine PSMD across the whole area, weighted values from each of the low, mean and high application zones can be summed using Eqn 26.

3.1.5.6 Seasonal deep percolation (SDP)

Seasonal deep percolation SDP includes all drainage whether from irrigation or precipitation. It is estimated from the balance of water not retained in the root zone, calculated after any surface losses have been accounted for (Eqn 13).

3.1.5.7 Seasonal irrigation deep percolation

Seasonal deep percolation resulting from irrigation (SDP_i) is a measure of the amount of irrigation water applied that drains from the soil profile. It is, in effect, seasonal application in-efficiency (Eqn 14).

$SDP_i > 0.0$ in the low quarter zone equates to seasonal irrigation adequacy > 1.0 as drainage has occurred.

To determine deep percolation across the whole area, weighted values from each of the low, mean and high application zones can be summed.

3.1.5.8 Drought induced yield loss

For most field crops, yield loss resulting from drought stress follows potential soil moisture deficit (PSMD) regardless of when in the season the stress occurs (Eqn 15).

Note: A possible exception is fruit trees and grape vines where deficit irrigation practices may be deliberately employed to control vegetative growth and or enhance crop quality without compromising yield.

3.1.5.9 Value of lost yield

The value of lost yield (cost of not irrigating correctly) is determined from the value of the crop and the amount of lost yield (Eqn 16).

Note that no account is made for loss of quality in the remaining crop using this formula.

3.1.5.10 Value of wasted water

Estimate the cost of water non-beneficially used from the amount of irrigation water lost through deep percolation, runoff and off-target application by the price paid for the water (Eqn 17).

Because SDP_i is calculated as a depth, a conversion is needed if water is charged by the cubic metre. Typically in New Zealand there is no charge on water itself, but any cost associated with its procurement, delivery or treatment may be included.

3.1.5.11 Value of wasted energy

The value of energy un-necessarily consumed is calculated from 'wasted' water, volumetric energy consumption and system efficiency factors using (Eqn 18). This integrates all energy losses, including those from poor headworks and mainline design.

Excess energy consumption can be reported in units of kWhr/mm/ha. Similarly, meaningful units for value of wasted energy is $/mm/ha.

3.1.5.12 Irrigation requirement

Irrigation requirement is given by crop water requirement plus any additional beneficial water requirement less received precipitation and stored soil moisture, calculated using (Eqn 19).

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