IRRIGATION
NEW ZEALAND

New Zealand Irrigation Technical Glossary

Contents

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1. Glossary

1.1 Terms and definitions

Adequacy of irrigation	A measure of the proportion of the target area for which the soil is restored to a target soil water content. This is calculated as the ratio of the mean low quarter depth applied, to the mean required (target) depth.
Application depth	The mean depth of water (mm) applied by an irrigation event during periods of peak irrigation demand. In some instances, such as for annual crops, the irrigation system may be required to meet a range of application depths to match progressive stages of crop development.
Applied depth (D_{app})	The volume of water applied divided by the wetted area (Aw). On a single plant or emitter scale volume is measured in litres, area in square meters giving applied depth in millimetres (mm).
Adjusted applied depth (d_i)	Adjusted volume of water caught in each collector in an array of collectors plus the average amount of water that evaporates while the water is in the collector, divided by the area of the collector opening (ISO).
Application efficiency	The percentage of applied water that is retained in the root zone, or in the target area, after an irrigation event.
Application intensity	The precipitation rate (mm/hr) of the irrigation system. **Average application intensity (R_a)** The precipitation rate averaged over the system's wetted footprint. For a rotating boom it is the machine flow rate divided by the wetting area calculated from the wetting diameter of the machine. For a stationary irrigators, it is the flow rate of all operational sprinklers divided by their combined wetted area. **Instantaneous application intensity (R_i)** The rate at which water is applied by an individual stream, from an individual outlet or nozzle, to a very small area. For a rotating boom it is the flow from a single outlet divided by the area being wetted at any instant by that outlet. For stationary irrigators it is the flow rate of all operational sprinklers divided by their combined wetted area.
Application uniformity	The spatial variability of application. This can be defined in a variety of ways. Common examples are: • Distribution Uniformity (DU) • Coefficient of Uniformity (CU) • Coefficient of Variation (CV).
Available water holding capacity (AWHC)	The amount of water that is able to be extracted by plant roots. This is calculated as the difference in moisture content between field capacity and permanent wilting point. It is often expressed as a depth of water contained within a specified depth of soil (e.g. mm/m) or as a volumetric percentage.
Backflow preventer	A device or devices installed in a pipeline to prevent fluid from flowing in reverse through the system.

Block	A downstream unit controlled by a single valve.
Capital cost	The overall system purchase and installation cost.
Coefficient of variation (Cv)	A statistical measure of variation within a sample.
Crop available water (depth) (CAW_D)	The rainfall equivalent depth of water (mm) available to specified crop from its root zone. The root zone depth in centimetres is shown as a subscript following the acronym; e.g. CAW40 is the crop available water (mm) in the 40cm deep root zone in a given soil.
Crop Irrigation Demand (CID)	The amount of water that would potentially be consumed by the irrigated crop in one week during peak evapo-transpiration conditions (m^3/ha/week).
Delivery hose	Soft or hard wall supply hose. Supply line that conveys water to a traveller irrigator.
Design area	The specific land area (e.g. in hectares) which the designer and the purchaser mutually understand is to be irrigated by the irrigation system.
Discharge coefficient (kd)	A dimensionless measure of the sensitivity of the emitter flow rate to changes in pressure.
Discharge exponent (x)	A dimensionless measure of the sensitivity of the emitter flow rate to changes in pressure.
Distance adjusted lowest quarter determination (D_{ajq})	Lowest quarter of collectors determined by ranking collected volumes and adjusting for distance from the pivot centre.
Distribution efficiency	A measure of how much of the water supplied to the Property is applied to the land. It is a function of losses incurred in the conveyance or distribution system, from the point of water abstraction to the application system.
Drainage depth	The potential volume of water that percolates beyond the root zone, based on peak irrigation demand. This is typically expressed as a volume per unit area (m^3/ha) or an equivalent depth per unit area (mm/ha).
Drive test pressure (P_d)	Pressure of a traveller irrigation machine measured at the inlet to the hydro-dynamic drive (FDIS).
Effective length (L_e)	Dimension parallel to the pipeline of the area to be irrigated by a linear move irrigation machine, conventionally calculated as the distance between the two most distant sprayers or sprinklers on the pipeline plus 75% of the wetted radius of the terminal sprayers or sprinklers. Where a proportion of the area under the pipeline is used for the water supply system and not crop production, that distance is excluded from the effective length (ISO).
Effective radius (re)	Radius of the circular field area to be irrigated by a centre pivot, conventionally calculated as the distance from the pivot point to the terminal sprayer or sprinkler on the pipeline plus 75% of the wetted radius of the terminal sprayer or sprinkler (ISO).
Effective root depth	The depth of soil profile that has enough rooting density for extraction of available water. Roots may be found at depths greater than this value but do not contribute significantly to water extraction.

Emission uniformity (EU)	A measure of variability in flow from emitters that is based on the coefficient of variation. Corresponds mathematically to the Christiansen coefficient.
Emitter	A device used to control the discharge from a lateral line at discrete or continuous points.
Emitter emission uniformity (EEU_{lq})	A measure of the variability of flow being received by individual plants. Derived from EU_{man}, EU_{defect} and the number of emitters per plant, equated to a low quarter uniformity equivalent.
End-gun	Set of one or more sprayer or sprinkler nozzles installed at end(s) of an irrigation machine to increase the irrigated area.
Evapotranspiration rate (ET)	The rate of water loss from a combined surface of vegetation and soil. It includes evaporation of water from the soil surface and from free water on plants, and transpiration by plants.
Equivalent applied depth (D_{zapp})	In micro irrigation, the volume applied to a plant, adjusted for the allocated ground area per plant.
Evapotranspiration rate (ET)	The rate of water loss from a combined surface of vegetation and soil. It includes evaporation of water from the soil surface and from free water on plants, and transpiration by plants.
Field capacity	The soil water content of well-drained soils after drainage from initially saturated soils has become negligible. The macro pores of the soil are filled with air and the micro pores hold water by capillary action. This is often considered to be equal to a soil water suction of 0.1 bar (10 kPa).
Headworks efficiency	A measure of the hydraulic performance of the intake structure, pump and headworks (excluding pump pressure and elevation differences) to indicate the extent of pressure loss in the water supply system between the water supply point and the mainline entry.
Hydraulic efficiency	A measure of the system hydraulic performance; it gives an indication of how much pressure is lost between the delivery (mainline entry) and discharge points (machine entry, hydrant, or take-off in drip-micro systems), excluding variations in elevation.
Infiltration rate	The movement of water into the soil profile. Measured as the rate (mm/hour, mm/day) at which a soil absorbs water. It varies with soil type, soil surface conditions, moisture content and time.
Inlet test pressure (P_i)	Pressure of a traveller irrigation machine measured at the inlet to the machine.
Irrigation requirement (IR)	Crop water requirement plus any additional beneficial water requirement less received precipitation and stored soil moisture.
Irrigation strip (Irrigation set)	The portion of a field irrigated by a sprayline or travelling irrigator set up in one location. It typically consists of a rectangle with an effective zone wetted by the water distribution system that significantly exceeds the dimensions of the strip and especially the width. Some overlapping of the wetted patterns of adjacent strips is often required to maintain an acceptable uniformity of water application over the entire field (~FDIS).
Irrigation strip width (E) (Strip spacing, Set spacing)	The spacing between strips, i.e. distance between two adjacent travel paths of the gun-cart or between two adjacent sprayline positions.

Irrigation system	This comprises all of the equipment required to transfer water from the water source to the crops in the design area.
Lateral	An emitting pipe with uniformly decreasing flow supplying water to points of application. **In micro systems** – The hose or tube, typically made of polyethylene, with emitters integrated or attached. **In spraylines, linear moves and pivots** – The pipe, typically made of steel or aluminium, on which sprinklers or sprayers are mounted.
Lateral filter	In-line filter or screen fitted at the beginning of each lateral line.
Lateral pressure (P_s)	Pressure available at a point in the lateral measured, while the system is in normal operation, using a pitot tube fitted to a gauge.
Line-source emitters	Water is discharged from closely spaced perforations, emitters or a porous wall along the lateral.
Low quarter irrigation adequacy (IA_{lq})	The ratio of the mean low quarter depth applied, to the mean target depth required across the field as a whole.
Mainline	A pipeline that carries treated water from system headworks to off-takes supplying a series of blocks.
Management allowable deficit (MAD)	This is a management decision that determines when to irrigate. The decision is based on a predetermined point at which crop available water is allowed to reduce to. Also known as the 'trigger point'. Note this term is not to be confused with the 'stress point'.
Manifold	A pipe that carries water from an off-take to a number of laterals.
Manufacturing emission uniformity (EU_{man})	Description of variation in flow resulting from manufacturing variability, determined from physical laboratory measurements at a standard temperature.
Mean field application depth (D_{mf})	Mean application depth collected along transverse lines after adjustment for evaporation and overlap from adjacent strips
Micro-irrigation system	Physical components required to apply water by micro-irrigation, consisting of a number of low pressure polyethylene laterals connected to manifolds and mainlines, and through which water is applied through point source emitters located along the laterals for further redistribution by the soil medium.
Operating system capacity (SC_{op})	Calculated on the 24 hour period total requirement being delivered in the time the system is actually operating. The flow of water per hectare of irrigated area that can be supplied in the time that the system is operating. See also *System capacity*.
Operating costs	The costs directly attributable to the operation of the irrigation system. • Labour to operate irrigation system • Energy costs of running the system • Maintenance costs. Operating cost should be expressed as cost per unit area ($/ha) and cost per unit volume of water ($/$m^3$).

Percentage wetted area	The area wetted as a percentage of the total crop area.
Permanent wilting point (WP)	The soil moisture content where plant growth stops. This is the lower limit of available water below which plant growth ceases completely. The soil matric potential at this point corresponds to about -1,500 kPa (-15 bar). The 'permanent wilting point' is generally governed by the amount of clay in the soil – the greater the amount of clay, the higher (% soil moisture) the 'permanent wilting point'.
Point-source emitters	Water is discharged from emission points that are individually and widely spaced, usually over 1 metre apart. Multiple-outlet emitters discharge water at two or more emission points.
Potential low quarter application efficiency (PAE_{lq})	A single event potential application efficiency estimated from field distribution uniformity and surface losses due to runoff and leakages. The value calculated can be used to determine the scheduling co-efficient.
Pressure regulation point	A location at which system pressure is managed to fall within defined parameters, typically through automatic or manually adjusted pressure regulation valves or by pipeline design. A pressure regulation point will normally be a block off-take or inlet to a manifold.
Productivity	The marginal increase in productivity resulting from the irrigation system. It is generally expressed as the increase based on mean annual irrigation demand per unit area ($/ha, may also be expressed as $/mm/ha), though for economic analysis, maximum and minimum values may also be of interest.
Profile available water (depth) (PAW_D)	The rainfall equivalent depth of extractable water within a specified depth in the soil. Extractable water is that held between field capacity and permanent wilting point. The soil depth in centimetres is shown as a subscript following the acronym; e.g. PAW60 is the profile available water in a given soil to a depth of 60cm. It is soil specific and independent of plant type or root depth.
Readily available water (RAW)	The water that is extractable by plants (plant type may be specified) without growth limitation from drought stress; taken as the difference between soil water at *field capacity* and at *stress point*.
Readily available water (depth) (RAWD)	The rainfall equivalent depth of 'readily available water' by a specified crop from its root zone. The root zone depth in centimetres is shown as a subscript following the acronym (e.g. RAW40 is the 'readily available water' in the 40cm deep root zone in a given soil).
Reference application intensity (R_i)	The mean rate of water application to the wetted area calculated from mean application depth, wetted area and irrigation duration.
Required system capacity (SC_{req})	The flow of water per hectare of irrigated area required to replace water used by the crop (plus any additional amounts for other purposes) in the time available.
Return interval (Return period)	The typical period between one irrigation event and the next. It is usually calculated for the most demanding period so that the irrigation system can meet water demand most of the time.

Return on water use	The marginal change in returns resulting from the irrigation system. It is generally based on mean annual irrigation demand, and incorporates cost and productivity elements above. Values can be expressed as returns per unit area or volume of water ($/ha or $/m^3). Values can be positive or negative, dependent on system costs, productivity and crop returns.
Rotator	A sprinkler that distributes water through a jet formed by parts that rotate at controlled speed.
Seasonal application efficiency (SAE)	The ratio of water retained in the root zone to water applied to the field, over a full irrigation season or year.
Seasonal deep percolation (SDP)	Includes all drainage whether from irrigation or precipitation.
Seasonal irrigation deep percolation (SDP_i)	A measure of the amount of irrigation water applied that drains from the soil profile. It is, in effect, seasonal application in-efficiency.
Scheduling co-efficient	Used to determine how much extra irrigation should be applied to ensure that most of the crop gets sufficient water. It accounts for variances and inefficiencies of application systems. It is common to use the reciprocal of the low quartile Distribution Uniformity to calculate the extra required. Multiplying irrigation need by the scheduling coefficient determines a target application depth that ensures that 7/8th of the crop will receive at least the required depth of irrigation (some will get considerably more).
Spinner	A sprinkler which distributes water, utilising free rotational movement of the sprinkler parts, in the form of a stream that breaks into droplets.
Sprayer	A sprinkler which sprays water, without rotational movement of the sprayer parts, in the form of fine jets or in a fan shape.
Sprinkler	Generic label for a device that distributes pressurised water through the air to a surrounding area.
Sprinkler package	A set of sprinklers with progressively larger sized nozzles along the length of a pivot irrigator.
Sprinkler pressure (P_S)	Pressure available at an individual sprinkler measured just upstream of the sprinkler or at the outlet, in the centre of the jet and 3mm from the orifice.
Station (Subunit)	Is one or more blocks operating together.
Stress point (SP)	The soil moisture content below which plant growth slows due to soil water being harder to uptake. This point is physiologically determined by the relationship between the plant roots and the soil characteristics. Also known as Critical deficit, or maximum allowable deficit. This physiological point can be used as the *management allowable deficit*. This point is different for different plants. Moisture stress is strongly related to soil matric potential, and generally occurs at approximately -50 kPa. However lab measurements commonly use -100 kPa so it is important to find out the correct value for particular soils in the field. It is often related to water content for irrigation management purposes. As a rule of thumb most plants will become stressed when about 50% of the total available water has been used.

Surface runoff	Water that does not immediately infiltrate into the soil and instead leaves the target zone by running off across the soil surface under gravity.
System capacity	Calculated on the basis of the system operating 24 hours per day. The flow of water per unit of irrigated area normally expressed as litres per second per hectare (L/s/ha) or mm per day (mm/d). See also *Operating system capacity*.
Test pressure (P_t)	Pressure of a linear move or centre pivot irrigation machine measured at the first available outlet downstream of the elbow or tee at the top of the inlet structure (ISO).
Total available water (TAW)	All the water that is extractable by plants (plant type may be specified); taken as the difference between soil water at *field capacity* and at *permanent wilting point*.
Travel path	Path within a strip along which the delivery tube or cable is laid and the gun-cart travels.
Travel path length (L_t)	Distance a traveller irrigation machine moves along its travel path, from starting point to stopping point, being not more than the length of the delivery tube for reel or self-propelled reel machines, and not more than twice the delivery hose length of traveller machines.
Wetted area (Aw)	The average soil area wetted by a single emitter, estimated in the root zone from the surface to a depth of <50cm.
Wetted radius (r_w)	Distance measured from the centre line of a sprayer or sprinkler to the furthest point at which the application intensity of the individual nozzle declines to approximately 1mm/hour, based on tests conducted when there is no wind.
Water Content (θ, theta)	The volumetric water content of soil as measured at a point in time (m^3 water/m^3 soil, mm water/mm soil).
Water distribution system	Sprinkling and travelling part of a traveller irrigation machine by which water is distributed and applied over a strip. E.g. sprinkler or gun-type sprinkler, combination of sprinklers and guns, boom with a set of sprinklers, sprayers or other kinds of water distribution devices. **Of a solid set or sprayline system** The arrangement of sprinklers used to distribute water across the area to be irrigated.
Water holding capacity (WHC)	The volumetric ratio of all water contained in a layer or depth of soil at field capacity, including that held too tightly for plants to access.

1.2 Abbreviations and symbols

A	area of the irrigated strip (m^2)
A_{plant}	ground area per plant
AE	Application efficiency
ASM	available soil moisture
A_w	Wetted area
A_{wetted}	wetted area per emitter
CU_c	Christiansen coefficient of uniformity
CU_r	Heermann and Hein coefficient of uniformity
C_v	coefficient of variation
Cv_{defect}	coefficient of variation due to emitter blockages, wear and tear
Cv_{man}	coefficient of variation due to manufacturing
Cv_{QPadj}	coefficient of variation of pressure adjusted flows
$\overline{D}$	mean depth of water collected by all collectors used in the data analysis
D_{ajq}	Distance adjusted lowest quarter determination
D_{app}	Applied depth
Dc	critical deficit
d_f	Mean field application depth
d_i	Adjusted depth
D_{inf}	depth water infiltrates
d_{lq}	low quarter applied depth
$\overline{D}_{mf}$	mean application depth based on system flow rate (mm)
d_{target}	targeted application depth
D_{wa}	average depth of water applied
D_{wr}	average depth of water retained
D_{Zmean}	mean depth applied to the whole field
D_{Zapp}	Equivalent applied depth
D_{Zmin}	minimum depth applied to a zone
DP	deep percolation in periods 1 to n
DU	Distribution uniformity
DU_{lq}	low quarter Distribution uniformity
E	Irrigation strip width
EC_{vol}	volumetric energy consumption
D_{Zapp}	Applied Depth in an area
EEU_{lq}	emitter variation factor
$E_{hydraulic}$	hydraulic efficiency
E_{pump}	pump efficiency
ET_{crop}	crop water use by evapo-transpiration
$ET_{limited}$	crop water use by a crop with restricted available soil moisture
EU	statistical emission uniformity
EU_{man}	manufacturer's emission uniformity
F_{dr}	drought response factor (%yield / mm PSMD)
$F_{drainage}$	effect of unequal system drainage
$F_{spacing}$	effect of spacing
F_{runoff}	proportion of water that leaves the field as a result of overland flow
FDU	Field Distribution Uniformity, an overall value incorporating a range of uniformity factors
GDU	Grid Distribution Uniformity, calculated from adjusted depths from a grid of collectors
I_i	Reference application intensity
IA_{lq}	low quarter irrigation adequacy
IR	irrigation requirement
K_{lq}	statistical distribution parameter for a normal distribution when low quarter is fraction used
K_d	emitter discharge coefficient
L_e	Effective length
L_t	Travel path length
MAD	management allowed depletion, maximum allowable deficit
n	number of items used in the data analysis
N_e	number of emitters per plant
n_{ER}	percentage of emitters that run after system shut down
OTA	depth equivalent of off-target application (mm)
p	operating pressure

P	precipitation
P_d	Drive test pressure
P_{energy}	price paid for energy ($/kWhr)
P_{field}	mean pressure determined from whole field pressure tests
P_i	Inlet test pressure
P_s	Sprinkler pressure
PAE_{lq}	Potential low quarter application efficiency
PET	Potential evapo-transpiration
$PSMD$	potential soil moisture deficit (mm)
P_t	Test pressure
P_{test}	pressure at which block was flow tested
P_w	price paid for water ($/m^3)
q	emitter flow rate
Q_{Em}	measured emitter flow
Q_{Padj}	Pressure adjusted emitter flow
Q_m	system flow rate (m^3/h)
Q_x	average flow per emitter
r_e	Effective radius
R_{ir}	reference application intensity (Assumed constant)
R_{it}	instantaneous application intensity for transect *i* (mm/hr)
r_w	Wetted radius
RI	Return interval
RO	depth equivalent lost through run-off (mm)
RAW	readily available water
s	standard deviation in the sample
SAE	seasonal application efficiency
S_{cc}	spacing between collector columns
SC_{des}	design system capacity
SC_{op}	operating system capacity
SC_{pot}	potential system capacity
SC_{req}	required system capacity
SDP	seasonal deep percolation
SDP_i	seasonal deep percolation from irrigation (mm)
SDU_{lq}	low quarter system distribution uniformity
SMD	soil moisture deficit
TER	average time for which those emitters run after system shut down
T_{irrig}	duration of an irrigation event
TAW	Total available water
$\overline{V}$	arithmetic average volume (or alternatively mass or depth) of water collected by all collectors used in the data analysis
Va_{lq}	distance adjusted average volume (or alternatively the mass or depth) of water collected in the lowest quarter of the field, calculated
V_i	volume (or alternatively the mass or depth) of water collected in the i^{th} container
V_{ww}	value of wasted water ($/mm/ha)
WHC	soil water holding capacity
WR_b	beneficial water requirement applied by irrigation system
X	emitter discharge exponent
$\overline{x}$	mean value from the sample
YL_{di}	drought induced yield loss
Y_{pot}	Potential Yield (t/ha)

1.3 Default factor values

1.3.1 CROP FACTORS

Crop factors (K_c) for a range of perennial crops grown in New Zealand are presented in Table 1 Tasman Regional Water Study, 2003. These account for an estimated ground cover factor (K_{gc})as well as crop specific factors (K_{crop}).

Table 1: Crop factors (K_c) by month

Month	Apples	Kiwifruit	Grapes	Berries	Stonefruit	Pasture
September	0.4	0.4	0.4	0.4	0.4	0.9
	0.4	0.4	0.4	0.4	0.4	0.9
October	0.4	0.5	0.61	0.4	0.4	0.9
	0.5	0.6	0.61	0.6	0.5	0.9
November	0.6	0.8	0.97	0.8	0.6	0.9
	0.7	0.9	0.97	0.9	0.65	0.9
December	0.7	1.0	0.83	1.0	0.7	0.9
	0.9	1.1	0.83	1.1	0.75	0.9
January	1.0	1.1	0.8	0.5	0.8	0.9
	1.0	1.1	0.8	0.5	0.8	0.9
February	1.0	1.1	0.7	0.4	0.8	0.9
	1.0	1.1	0.7	0.4	0.7	0.9
March	0.95	1.1	0.7	0.4	0.6	0.9
	0.9	1.0	0.7	0.4	0.4	0.9
April	0.4	0.8	0.7	0.4	0.4	0.9
	0.4	0.4	0.7	0.4	0.4	0.9
May	0.4	0.4	0.6	0.4	0.4	0.9
	0.4	0.4	0.6	0.4	0.4	0.9
June	0.4	0.4	0.4	0.4	0.4	0.9
	0.4	0.4	0.4	0.4	0.4	0.9
July	0.4	0.4	0.4	0.4	0.4	0.9
	0.4	0.4	0.4	0.4	0.4	0.9
August	0.4	0.4	0.4	0.4	0.4	0.9
	0.4	0.4	0.4	0.4	0.4	0.9

Source: Tasman Regional Water Study – Technical Report Stage 1: Land & Climate Suitability for Irrigated Crops. Prepared for TRWAC by Lincoln Environmental (Report No 4487/1, August 2003).

Table 2: Proportion of potential transpiration from sowing to full ground cover

Effective Ground Cover % / Crops	Beans	Peas	Potatoes	Corn	Lucerne	Pasture
10	0.2	0.2	0.1	0.2	0.35	0.9
20	0.23	0.25	0.15	0.25	0.45	0.9
30	0.3	0.3	0.2	0.3	0.6	0.9
40	0.4	0.4	0.3	0.4	0.7	0.9
50	0.5	0.5	0.4	0.5	0.8	0.9
60	0.65	0.65	0.55	0.6	0.9	0.9
70	0.75	0.75	0.65	0.7	1.0	0.9
80	0.9	0.85	0.75	0.8	1.0	0.9
90	1.0	1.0	0.85	0.9	1.0	0.9
100	1.05	1.05	0.9	0.95	1.0	0.9

Source: Davoren, A. 2002 Planning and monitoring irrigation rotations. Report for LandWISE.

1.3.2 MANAGEMENT ALLOWABLE DEFICIT (MAD)

Approximate values for management allowable deficit for a range of common crops are presented in (Table 3).

Table 3: Management allowable deficit (MAD) for a range of crops on silt loam

Crop	MAD (% AWC)
Ryegrass pasture	30–35
Spring barley	60–65
Peas	35–45
Potatoes	30–45
Lucerne	70–75
Onions	30–60
Pipfruit	55–65
Grapes	70–80

Source: Davoren, A. 2002 Planning and monitoring irrigation rotations. Report for LandWISE.

2. Calculations

2.1 Standard formulae

2.1.1 WATER AND SOIL CALCULATIONS

Eqn 1: Crop evapotranspiration (ET_{crop})

The crop water requirement calculated is described as crop-adjusted evapo-transpiration (ET_{crop}), by adjusting PET to account for crop specifics and ground cover.

$$ET_{crop} = PET \times Kc$$

Where:

ET_{crop}	is crop-adjusted evapo-transpiration (mm/d)
PET	is reference potential evapo-transpiration (mm/d)
K_c	is the crop water use co-efficient

And:

$$K_c = K_{crop} \times K_{gc}$$

Where:

K_{crop}	is crop specific water use factor
K_{gc}	is the ground cover fraction

Eqn 2: Crop water use ($ET_{limited}$)

Actual crop water use is a function of PET, limited by soil available water. Potential water use in any period is given by ET_{crop}. Where soil moisture is limited, the actual water use will be the maximum of ETcrop or available soil moisture (ASM).

$$ET_{limited} = \textit{greater of: } ET_{crop} \textit{ or } ASM + (P + I)$$

Where:

$ET_{limited}$	is actual crop water use
ET_{crop}	is crop water use by evapo-transpiration
ASM	is available soil moisture
I	is beneficial water requirement applied by irrigation system
P	is precipitation

Eqn 3: Potential soil moisture deficit (PSMD)

Potential crop growth is reduced in any period where crop water use is restricted due to low soil water availability. PSMD is a measure of moisture stress experienced by a crop, relative to the climatic potential moisture use. PSMD can be estimated from Potential crop water use (ET_{crop}) and actual (water limited) crop water use ($ET_{limited}$).

$$PSMD = ET_{crop} - ET_{limited} : ET_{crop} > ET_{limited}$$

Where:

$PSMD$	is potential soil moisture deficit in any period where SMD>Dc
ET_{crop}	is crop water use by evapo-transpiration
$ET_{limited}$	is actual crop water use

2.1.2 SYSTEM CAPACITY CALCULATIONS

Eqn 4: Design system capacity (SC_{des})

The flow of water per hectare of irrigated area determined by the designer of the system. Presumed to be the basis for the subsequent design. The value would normally be selected based on need to replace water used by the crop plus any additional amounts for other purposes. However water source limitations or regulatory maxima may necessitate a lower value.

Eqn 5: Required system capacity (SC_{req})

The flow of water per hectare of irrigated area required to replace water used by the crop (plus any additional amounts for other purposes) in the time available.

$$SC_{des} = \frac{PET \times K_c \times 24 \times 3600}{10{,}000} \times \frac{T_{irrig}}{T_{rot}}$$

Where:

SC_{des}	is design system capacity (L/s/ha)
PET	is reference potential evapo-transpiration (mm/d)
K_c	is the crop water use co-efficient
T_{irrig}	is time irrigating per rotation (hrs)
T_{rot}	is time per rotation (hrs)

Eqn 6: Potential system capacity (SC_{pot})

The flow of water per hectare of irrigated area that can be supplied if the system as operating was run for 24 hours per day. It is calculated from measured or calculated system flow rate divided by the measured or calculated area irrigated.

$$SC_{pot} = \frac{Q_{sys}}{A_{irrig}}$$

Where:

SC_{pot} is potential system capacity (L/s/ha)

Q_{sys} is the mean system flow rate (L/s)

A_{irrig} is area irrigated (ha)

Eqn 7: Operating system capacity (SC_{op})

The flow of water per hectare of irrigated area that can be supplied in the time that the system is operating. It is the potential system capacity adjusted by the ratio of time irrigating per rotation to rotation time.

$$SC_{op} = SC_{pot} \times \frac{T_{irrig}}{T_{rot}}$$

Where:

SC_{op} is operating system capacity (L/s/ha)

SC_{pot} is potential system capacity (L/s/ha)

T_{irrig} is time irrigating per rotation (hrs)

T_{rot} is time per rotation (hrs)

2.1.3 EFFICIENCY CALCULATIONS

Eqn 8: 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.

$$SAE = \frac{\overline{D}_{wr}}{\overline{D}_{wa}} \times 100$$

Where:

SAE is the seasonal application efficiency

Dwr is the average depth of water retained

Dwa is the average depth of water applied

Eqn 9: Weighted seasonal application efficiency (SAE_w)

The overall SAE is a weighted average of these calculated values.

$$SAE_w = \frac{AE_{lq} + 2AE_{mean} + AE_{hq}}{4} \times 100$$

Where:

$SAEw$ is weighted seasonal application efficiency

lq is low quarter zone

$mean$ is field average zone

hq is high quarter zone

Eqn 10: Potential low quarter application efficiency (PAE_{lq})

The single event potential application efficiency is estimated from field distribution uniformity and surface losses due to runoff and leakages. The value calculated can be used to determine the scheduling co-efficient.

$$PAE_{lq} = DU_{lq} \times (1.0 - (RO + SL))$$

Where:

PAE_{lq} is potential low quarter application efficiency

DU_{lq} is low quarter distribution uniformity

RO is field runoff

SL is system leakages

Eqn 11: Low quarter irrigation adequacy (IA_{lq})

The ratio of the mean low quarter depth applied, to the mean target depth required across the field as a whole.

$$AD_{lq} = \frac{d_{lq}}{d_{target}}$$

Where:

IA_{lq} is low quarter irrigation adequacy

d_{lq} is low quarter applied depth

d_{target} is targeted application depth

Eqn 12: Seasonal potential soil moisture deficit ($PSMD_{season}$)

Seasonal PSMD is calculated by summing period PSMD's calculated as in Eqn 3.

$$PSMD_{season} = \Sigma\,(PSMD_1 : PSMD_n)$$

Where:

$PSMD_{season}$	is seasonal potential soil moisture deficit
$PSMD_1$	is potential soil moisture deficit in the first period
$PSMD_n$	is potential soil moisture deficit in the nth period

And where:

$PSMD_2 > PSMD_1$

Eqn 13: 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.

$$SDP = \Sigma\,(DP_1 : DP_n)$$

Where:

SDP	is seasonal deep percolation
DP	deep percolation in periods 1 to n

Eqn 14: Seasonal irrigation deep percolation (SDP_i)

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

$$SDP_i = (1 - SAE)$$

Where:

SDP_i	is seasonal deep percolation from irrigation
SAE	is seasonal application efficiency (Eqn 8)

Eqn 15: Drought induced yield loss (YL_{di})

Calculated from potential (farmer expected) yield, PSMD and the drought response factor.

$$YL_{di} = Y_{pot} \times PSMD \times F_{dr}$$

Where:

YL_{di}	is drought induced yield loss
Y_{pot}	is the Potential Yield (t/ha)
$PSMD$	is potential soil moisture deficit (mm)
F_{dr}	is the drought response factor (%yield / mm PSMD)

Eqn 16: Value of lost yield (YL_v)

The value of lost yield is determined from the value of the crop and the amount of lost yield.

$$YL_v = YL_{di} \times Price$$

Where:

YL_v	is the value of lost yield ($/ha)
YL_{di}	is drought induced yield loss
$Price$	is price paid per unit yield

Eqn 17 Value of wasted water (V_{ww})

One estimate of the cost of water non beneficially used is to multiply the amount of irrigation water lost through deep percolation, runoff and off-target application by the price paid for the water.

$$V_{ww} = 10 \times (SPD_i + RO + OTA) \times P_w$$

Where:

V_{ww}	is the value of wasted water ($/mm/ha)
SDP_i	is seasonal deep percolation from irrigation (mm)
RO	is depth equivalent lost through run-off (mm)
OTA	is depth equivalent of off-target application (mm)
P_w	is the price paid for water ($/m^3)
10	constant converting m^3/ha to mm/ha

Eqn 18: Value of wasted energy (V_{we})

$$V_{we} = \frac{10 \times (SPD_i + RO + OTA) \times (EC_{vol} \times P_{energy})}{(E_{pump} \times E_{hydraulic})}$$

Where:

V_{we}	is the value of wasted water ($/mm/ha)
SDP_i	is seasonal deep percolation from irrigation (mm)
RO	is depth equivalent lost through run-off (mm)
OTA	is depth equivalent of off-target application (mm)
EC_{vol}	is volumetric energy consumption
P_{energy}	is the price paid for energy ($/kWhr)
E_{pump}	is pump efficiency
$E_{hydraulic}$	is hydraulic efficiency
10	constant converting m^3/ha to mm/ha

Eqn 19: Irrigation requirement (IR)

Irrigation requirement is given by crop water requirement plus any additional beneficial water requirement less received precipitation and stored soil moisture.

$$IR = \frac{(ET_{crop} \times WR_b)}{(DU_{lq})} (P + ASM)$$

Where:

IR	is irrigation requirement
ET_{crop}	is crop water use by evapo-transpiration
WR_b	is beneficial water requirement applied by irrigation system
P	is precipitation
ASM	is available soil moisture
DU_{lq}	is low quarter Distribution uniformity

2.1.4 BASE CALCULATIONS

Eqn 20: Coefficient of variation (C_v)

The coefficient of variation is a statistical measure of variation within a sample, calculated using the formula:

$$C_v = \frac{s}{\bar{x}}$$

Where:

C_v	is the coefficient of variation
s	is the standard deviation in the sample
	is the mean value from the sample

Eqn 21: Standard deviation from the mean (s)

$$s = \left[\frac{\sum_{i=1}^{n} \times (x_1 - \bar{x})^2}{n - 1} \right]^{1/2}$$

Where:

x_i	is the performance of an individual within the sample
i	is a number assigned to identify a particular individual
n	is the number of individuals in the sample

A C_v of 0.05 implies 68% of flows are within 5% of the mean, and 95% of flows within 10% of the mean (DAM).

Eqn 22: Emitter pressure flow relationship

The relationship between emitter operating pressure and flow rate is given by the equation:

$$q = K_d \, p^x$$

Where:

q	is the emitter flow rate
K_d	is the emitter discharge coefficient
p	is operating pressure
x	is the emitter discharge exponent

Eqn 23: Emitter discharge exponent

The emitter discharge exponent can be determined using the formula (DAM):

$$x = \frac{\log \left(\frac{q_1}{q_2} \right)}{\log \left(\frac{p_1}{p_2} \right)}$$

Where:

x	is the emitter discharge exponent
p_1 & p_2	are pressures
q_1 & q_2	are flows at p_1 and p_2 respectively.

The coefficient is typically between 0 and 1, often in the range 0.5 – 0.7.

Note: A coefficient value = 0 describes an emitter where flow is totally independent of pressure, and a value = 1 describes an emitter where flow increases directly in proportion to pressure.

Eqn 24: Emitter discharge coefficient (K_d)

The emitter discharge coefficient is determined from the rearranged pressure flow equation:

$$K_d = \frac{q}{p^x}$$

Where terms are as above.

Eqn 25: Manufacturer's emission uniformity (EU_{man})
Manufacturer's emission uniformity is determined from physical laboratory measurements at a standard temperature.

Note: Values of EU_{man} are typically reported as a percentage value, but should be converted to a decimal.

EU_{man} is derived from the coefficient of variation using the formula:

$$EU_{man} = 1.0 - CV_{man}$$

Where:

EU_{man} is manufacturer's emission uniformity

Cv_{man} is the coefficient of variation in manufacturing

2.1.5 COMBINATION FORMULAE

Eqn 26: Weighted averages
When combining data from seasonal irrigation estimates that split into low quarter, mean and high quarter calculations it is necessary to apply a weighted average method.

Eqn 27: Field Mean Value

$$X_{field} = \frac{X_{lq} + 2X_{mean} + X_{hq}}{4}$$

Where:

X_{field} is the overall result for the field for any particular parameter, X

X_{lq} is the result for the area receiving the low quarter irrigation

X_{mean} is the result for the area receiving the mean irrigation

X_{hq} is the result for the area receiving the high quarter irrigation

See also Eqn 9.

Eqn 28: Clemmens-Solomon
Combination of uniformity components where their influence is multiplicative should use the Clemmens-Solomon statistical procedure:

$$SDU_{lq} = \left[1 - \sqrt{(1-DU_1)^2 + (1-DU_2)^2 + (1-DU_n)^2}\,\right]$$

Where:

SDU_{lq} is low quarter system distribution uniformity

DU_n is low quarter distribution uniformity of factor n

Examples include combining Pressure DU and emitter manufacturing DU.

Eqn 29: DU of combined populations
Note: Where several populations are to be combined to determine an overall uniformity, the all data should be aggregated and a new DU determined from the whole data set.

It is not correct to take a simple mean of several DU's to find an overall value.

If, for example, three areas (three drip blocks or three traveller transects) each had perfect DU (DU=1.00) but the measured application depths were different in each, the overall DU is not DU=1.00, but some lower value.

2.1.6 UNIFORMITY CALCULATIONS

Eqn 30: Distribution uniformity (DU_{lq})
This Code adopts the low quarter distribution uniformity ratio. The low quarter distribution uniformity coefficient formula is:

$$DU_{lq} = \frac{\overline{V_{lq}}}{\overline{V}}$$

Where:

DU_{lq} is the lowest quarter distribution uniformity coefficient

V_{lq} is the average volume (or alternatively the mass or depth) of water collected in the lowest quarter of the field

$\overline{V}$ is the average volume (or alternatively mass or depth) of water collected by all collectors used in the data analysis

Eqn 31: Distance adjusted lowest quarter determination (D_{adj})
The distance adjusted lowest quarter of collectors is determined by ranking collected volumes and adjusting for distance from the pivot centre.

1. Rank all evaporation adjusted collector volumes, V.
2. Multiply each adjusted volume by its distance from the centre (S) to give the Distance adjusted volume V_a.
3. Sum distances from pivot centre (S_i) cumulatively from the lowest value.
4. Divide by four to determine the low quartile point.
5. The low quarter is all the results at or below the low quartile point.

Eqn 32: Centre pivot radial uniformity

The low quarter distribution uniformity coefficient formula is adjusted to account for increasing field areas represented by collectors placed further from the pivot centre.

$$DU_{lq} = \frac{\overline{Va_{lq}}}{\overline{Va}}$$

Where:

DU_{lq} is the lowest quarter distribution uniformity coefficient

Va_{lq} is the distance adjusted average volume (or alternatively the mass or depth) of water collected in the lowest quarter of the field, calculated as:

Note: Average distance adjusted depth $ADD_{Adj} = V_a$ / Collector mouth area (m^2)

Eqn 33: Distance adjusted average volume

$$\overline{Va_{lq}} = \frac{\sum_{i=1}^{n/4} Va_i \ S_i}{\sum_{i=1}^{n/4} S_i}$$

Where:

i is a number assigned to identify a particular collector, normally beginning with the collector with the lowest catch volume (i = 1) and ending with i = n for the collector with the highest catch volume

n is the number of collectors used in the data analysis

Si is the distance of the ith collector from the pivot point

is the distance adjusted average volume (or alternatively mass or depth) of water collected by all collectors used in the data analysis, calculated as:

$$\overline{Va_{lq}} = \frac{\sum_{i=1}^{n} Va_i \ S_i}{\sum_{i=1}^{n} S_i}$$

Eqn 34: Christiansen coefficient (CU_c)

The Christiansen formula is:

$$CU_c = \left[1 - \frac{\sum_{i=1}^{n} \left| V_i - \overline{V} \right|}{\sum_{i=1}^{n} V_i} \right]$$

Where:

CU_c is the Christiansen coefficient of uniformity

n is the number of collectors used in the data analysis

i is a number assigned to identify a particular collector

Vi is the volume (or alternatively the mass or depth) of water collected in the ith container

$\overline{V}$ is the arithmetic average volume (or alternatively mass or depth) of water collected by all collectors used in the data analysis, calculated as:

$$\overline{V} = \frac{\sum_{i=1}^{n} V_i}{n}$$

Eqn 35: Heermann-Hein uniformity coefficient

The Christiansen uniformity coefficient formula is adjusted as proposed by Heermann and Hein to account for increasing field areas represented by collectors placed further from the pivot centre.

The Heermann and Hein formula is:

$$CU_r = \left[1 - \frac{\sum_{i=1}^{n} \left| V_i - \overline{V_w} \right| S_i}{\sum_{i=1}^{n} \left| V_i S_i \right|} \right]$$

Where:

CU_r is the Heermann and Hein coefficient of uniformity

n is the number of collectors used in the data analysis

i is a number assigned to identify a particular collector, normally beginning with the collector located nearest the pivot point (i = 1) and ending with i = n for the collector furthest from the pivot point

V_i is the volume (or alternatively the mass or depth) of water collected in the ith container

S_i is the distance of the ith collector from the pivot point

$\overline{V_w}$ is the weighted average volume (or alternatively mass or depth) of water collected, calculated as:

$$\overline{V_w} = \frac{\sum_{i=1}^{n} V_i S_i}{\sum_{i=1}^{n} S_i}$$

Eqn 36: Emission uniformity (EU)

Corresponds mathematically to the Christiansen coefficient and is based on the coefficient of variation using the formula:

$$EU = (1.0 - C_v)$$

Where:

EU is the statistical emission uniformity

C_v is the coefficient of variation

Eqn 37: Emission vs Distribution Uniformity

Emission uniformity (EU) is related to low quarter distribution uniformity (DU_{lq}) by the equation:

$$DU_{lq} = 1 - (1.27C_v) \text{ or } DU_{lq} = 1 - 1.27(1 - EU_{stat})$$

The factor k_{lq} = 1.27 equates the statistical uniformity coefficient to a low quarter uniformity equivalent assuming a normal distribution.

Eqn 38: Emitter emission uniformity (EEU_{lq})

$$EEU_{lq} = 1 - 1.27\left(\frac{\sqrt{(Cv_{man})^2 + (Cv_{defect})}}{(\sqrt{n})}\right)$$

Where:

EEU_{lq} is the emitter emission uniformity

Cv_{man} is the coefficient of emitter manufacturing variation

Cv_{defect} is the mean coefficient of variation due to blockages, wear and tear determined from emitter tests 1, 3 & 4

n is the number of emitters per plant

The factor k_{lq} = 1.27 equates the statistical uniformity coefficient to a low quarter uniformity equivalent assuming a normal distribution.

Eqn 39: Uneven drainage coefficient ($F_{drainage}$)

$$F_{drainage} = 1 - \left(\frac{n_{ER}}{100}\left(\frac{(T_{ER})}{(T_{irrig})}\right)\right)$$

Where:

$F_{drainage}$ is the effect of unequal system drainage

n_{ER} is the percentage of emitters that run after system shut down

T_{ER} is the average time for which those emitters run after system shut down

T_{irrig} is normal duration of a scheduled irrigation event

Eqn 40: Uneven spacing coefficient ($F_{spacing}$)

$$F_{spacing} = \frac{(Dz_{min})}{(Dz_{mean})}$$

Where:

$F_{spacing}$ is the effect of spacing

DZ_{min} is the minimum depth applied to a zone

DZ_{mean} is the mean depth applied to the whole field

Eqn 41: Pressure adjusted emitter flow (QPadj)

$$Q_{Padj} = Q_{Em}\left(\frac{(P_{field})^x}{(P_{test})^x}\right)$$

Where:

Q_{Padj} is Pressure adjusted emitter flow

Q_{Em} is measured emitter flow

P_{field} is mean pressure determined from whole field pressure tests

P_{test} is pressure at which block was flow tested

x emitter discharge exponent

Eqn 42: Emitter defect coefficient of variation (Cv_{defect})

$$C_{vdefect} = \sqrt{(C_{vQPadj})^2 - (C_{vman})^2}$$

Where:

Cv_{defect} is the effect of emitter blockages, wear and tear

Cv_{QPadj} is the coefficient of variation of pressure adjusted flows

Cv_{man} is the manufacturer's coefficient of variation of emitters

Note: The Clemmens – Solomon equation (Eqn 29) causes problems here if the measured field uniformity is better than CV_{man} as it would require a square root of a negative number.

Eqn 43: Design Uniformity (EU_{des})

$$EU_{design} = \left[1.0 - \frac{1.27C_{vman}}{\sqrt{n}}\right]\frac{q_m}{q_a}$$

Where:

EU_{des} is design emission uniformity

Cv_{man} is the manufacturer's coefficient of variation of emitters

n is the number of emitters per plant

q_m is the mean low quarter emitter discharge due to the mean low quarter pressure

q_a is the overall mean emitter discharge

(Keller and Karmeli, 1974: ASAE 405.1)

2.1.7 APPLICATION CALCULATIONS

Eqn 44: Mean system application depth (Dmf)

$$D_{mf} = \frac{Q_m \times T_{irrig}}{A}$$

Where:

D_{mf}	mean application depth based on system flow rate (mm)
Q_m	system flow rate (L/h)
T_{irrig}	is the duration of an irrigation event (hours)
A	area of the irrigated strip (m^2)

Eqn 45: Infiltration depth (micro and long-lateral)

$$D_{inf} = \frac{Q_{\bar{x}} \times T_{irrig}}{A_{wetted}}$$

Where:

D_{inf}	is the depth water infiltrates (mm)
Q_x	is the average flow per emitter (L/h)
T_{irrig}	is the duration of an irrigation event (h)
A_{wetted}	is the wetted area per emitter (m^2)

Eqn 46: Equivalent applied depth (micro)

$$D_{zapp} = \frac{Q_{\bar{x}} \times n_e \times T_{irrig}}{A_{plant}}$$

Where:

Dz_{app}	is the Applied Depth in an given zone, z
$Q_{\bar{x}}$	is the average flow per emitter
N_e	is the number of emitters per plant
T_{irrig}	is the duration of an irrigation event
A_{plant}	is the ground area per plant

Eqn 47: Reference application intensity (Rir)

$$R_{ir} = \frac{\bar{D}}{T_{irrig}}$$

Where:

R_{ir}	is the reference application intensity (Assumed constant)
$\bar{D}$	is mean depth of water from all collectors used in analysis
T_{irrig}	is the duration of an irrigation event

Eqn 48: Instantaneous application intensity (R_{it})

$$R_{it} = \bar{D}_i \left(\frac{V_i}{A_w} \right)$$

Where:

R_{it}	is instantaneous application intensity for transect i (mm/hr)
$\bar{D}_i$	is mean application depth applied to strip width at transect i (mm)
A_w	is wetting area of distribution system (m)
V_i	is mean travel speed of the distribution system at transect i (m/h)

Eqn 49: Instantaneous application intensity – linear move (R_{il})

$$R_{il} = 3{,}600 \left(\frac{Q_m}{L_e \times W} \right)$$

Where:

R_{il}	is the instantaneous application intensity (mm/hr)
W	is the wetted width (diameter) of nozzle pattern (m)
Q_m	is the Machine discharge (L/s)
L_e	is the effective length of lateral (m)

Eqn 50: Instantaneous application intensity – centre pivot (R_{ip})

$$R_{ip} = 3{,}600 \left(\frac{Q_f}{r_e^2} \right) \frac{r}{W}$$

Where:

R_{ip}	is the instantaneous application intensity at radius, r (mm/hr)
r	is radial distance from pivot centre to point under study (m)
W	is the wetted width (diameter) of nozzle pattern at r (m)
Q_f	is the discharge for the full irrigated circle (L/s)
r_e	is the effective radius of the full irrigated circle (m)

For the maximum average application intensity along a centre pivot system, water application intensity reaches its maximum at the furthest distance from the pivot point (assuming no end gun) that is $r = r_e$

Therefore:

$$R_{max} = 3{,}600 \left(\frac{Q_f}{r_e W} \right)$$

Note: The Application Intensity at 2/3rd radius is the average for the irrigated circle as a whole.

Eqn 51: Application intensity of micro-irrigation

$$R_{im} = \frac{\bar{q}}{d_e \times d_r}$$

Where:

R_{im}	is the Mean application intensity (mm/h)
$\bar{q}$	is the mean emitter discharge for the block (L/h)
d_e	is the distance between emitters on a lateral (m)
d_l	is the distance between laterals (m)

2.1.8 ADDITIONAL CALCULATIONS

Eqn 52: Machine speed, (S)

$$S_i = 60 \times \left[\frac{D_i}{T_i}\right]$$

Where:

Si	is machine travel speed at position, i (m/minute)
D_i	is a selected travel distance at position i (m)
Ti	is the time taken for machine to move distance D_i (seconds)
60	is constant changing seconds to minutes

Eqn 53: Speed difference for travelling irrigator (DV_{max})

$$DV_{max} = \left[\frac{S_{max} - S_{min}}{\bar{S}}\right]$$

Where:

DV_{max}	max deviation in travel speed relative to the mean
S_{max}	maximum machine speed
S_{min}	minimum machine speed
$\bar{S}$	mean machine speed (m/h)

Eqn 54: Hydraulic efficiency (E_{hyd})

$$E_{hydx} = 100 - \left[\frac{(P_{HW} + (EL_{HW} \times 9.81)) - (P_{EI} + (EL_{EI} \times 9.81))}{P_{HW}}\right] \times 100$$

Where:

E_{hydx}	is hydraulic efficiency (%)
P_{HW}	is pressure after the headworks (kPa)
EL_{HW}	is elevation at headworks (m)
P_{EI}	is pressure at entry to irrigator/distribution system (kPa)
EL_{EI}	is elevation at entry to irrigator/distribution system (m)

Eqn 55: Headworks efficiency (E_{hw})

$$E_{HW} = 100 - \left[\frac{P_{PD} - P_{HW}}{P_{PD}}\right] \times 100$$

Where:

E_{HW}	is hydraulic efficiency (%)
P_{PD}	is pressure after the pump (kPa)
P_{HW}	is pressure after the headworks (kPa)

Eqn 56: Pumping efficiency (E_{pump})

$$E_{pump} = 100 - \left[\frac{(Q_{sys} \times 60) - (P_{NP}/9.81)}{P_{PD}}\right] \times 100$$

Where:

E_{pump}	is pumping efficiency (%)
Q_{sys}	is pumped volume (system flow (from water meter))
P_{NP}	is nett pump pressure (kPa)
P_{PD}	is pressure after the pump (kPa)

Eqn 57: Theoretical return interval (RI_{the})

The theoretical return interval is calculated from the readily available water and the crop water use. Crop water use is determined from Peak PET and crop factor.

$$RI_{ther} = \left[\frac{RAW}{Peak\ PET \times Crop\ Factor}\right]$$

Eqn 58: Application Efficiency

$$AE = \frac{100\ (1 + CU_c)}{2}$$

Where:

CU_c	is the Christiansen coefficient of uniformity

Note: This only applies to spray irrigation applications that return soil moisture to field capacity.

Eqn 59: Well flow-drawdown relationship

An approximate relationship between drawdown in a well and flow rate is given by the equation:

$$DD = K_d\, Qx$$

Where:

DD	is the well drawdown
K_d	is the discharge coefficient
Q	is the flow rate
x	is the well exponent

Eqn 60: Hazen Williams formula

The Hazen Williams equation is an empirical formula which relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by friction.

$$H = \frac{1.213 \times 10^{10} \times Q^{1,852} \times L}{C^{1,852} \times d^{4.871}}$$

Where:

H head loss in m water/m pipe

Q is the flow (l/s)

d is the pipe internal diameter (mm)

C is the Hazen Williams roughness

- For very rough, rusty situations, use a C = 100.
- For moderate, average conditions, use a C = 120.
- For smooth situations, use a C = 140

2.2 Evaporation from collectors

2.2.1 ACCOUNT FOR EVAPORATION

Account for evaporation by adjusting measured volumes from test collectors by relative losses from the control collector(s).

Note: Evaporation from free water can exceed 1mm per hour around midday in summer. If low volumes are collected in wide collectors, a difference in collection time of one hour can generate significant errors.

2.2.2 MINIMISE EVAPORATION INFLUENCE

Steps to minimise evaporation losses should be taken as first preference.

The uniformity test should be conducted during periods that minimise the effect of evaporation, such as at night or early morning or in winter months. Record the time of day, estimated or measured temperature and humidity when the test is conducted (ISO, Cal, IEP).

2.2.3 EXCEPTIONS

There is a potential problem estimating evaporation effects when conducting uniformity tests of rotating boom and big gun travelling irrigators. The wetting pattern of such irrigators describes a circle or arc, so collectors placed at the outer limits of the wetted strip width will cease receiving water well before those in the centre.

The time between the outside and inside collectors exiting the wetting area can vary considerably. Adjusting collectors by the method prescribed above will not accurately reflect evaporative effects on caught volume (depth).

The recommendation is to collect and measure caught volumes (depths) in collectors as soon as they are outside the wetting area. This minimises evaporative effects, so no adjustment is required.

2.2.4 ESTABLISH CONTROL COLLECTORS

If adjusting for evaporation loss, place a control collector (ISO specifies a minimum of three) in a representative location upwind of the test area. At the end of the test period, add the approximate average catch volume of water to the control collector and record the time. After measuring all test collectors, measure the volume in the control collector and record the time.

Measure and record the volume of water in each collector as soon as possible after the collector is no longer within the range of the water pattern. If adjusting for evaporation loss, record the time from when each collector is in range of the water pattern until collector volume is measured.

2.2.5 MEASURE COLLECTED VOLUMES

Measure and record the volume of water in each collector as soon as possible after the collector is no longer within the range of the water pattern. If adjusting for evaporation loss, record the time from when each collector is in range of the water pattern until collector volume is measured.

When all test collectors have been measured, measure the volume in the test collector. If multiple test collectors are used determine the average loss.

2.2.6 ACCOUNTING FOR EVAPORATION LOSSES

Note: Method to adjust test collector measurements to account for evaporation losses

1. Assume the evaporation rate from the control collector(s) was constant and determine the volume lost per minute.
2. Convert the volume lost to an equivalent depth per minute.
3. Calculate loss in the period until collector volume was read
4. Add the calculated loss to the calculated applied depth in each test collector.

Worked example

1. Assume the test measurement took 50 minutes, and 250 mL of 1000 mL added to the control collector evaporated.

   Therefore:

   125mL/1000mL = 0.125L/L evaporated in 50 minutes

   or

   0.125/50 min = 0.0025 L/min

2. The diameter of the control collector is 250mm.

   Therefore:

   Area of collector mouth = *Pi* x ($0.25m^2/4$)
   = $0.049\ m^2$

   Therefore:

   Evaporation rate = 0.0025 L/min / $0.049\ m^2$
   = 0.05 mm/min

3. Assume the first test collector (diameter 250mm) was measured 25 minutes after irrigation stopped, and the measured volume was 300 ml.

   Therefore:

   Applied depth = 0.300 L / $0.049\ m^2$
   = 6.12 mm

   Evaporation:
   0.05 mm/min x 25min = 1.25 mm evaporated

   Adjusted Applied Depth:
   6.12 + 1.25 mm = 7.37 mm

This calculation must be repeated for each collector, so a prepared computer program is strongly recommended.

2.3 Overlapping systems

2.3.1 OVERLAP ACCOUNTING

For water distribution systems intended to operate with areas of overlap, application depths must be adjusted to account for overlap effects.

Translate the out-of-strip data in each collector column (transverse collector line) by a distance equal to the Irrigated strip width (E).

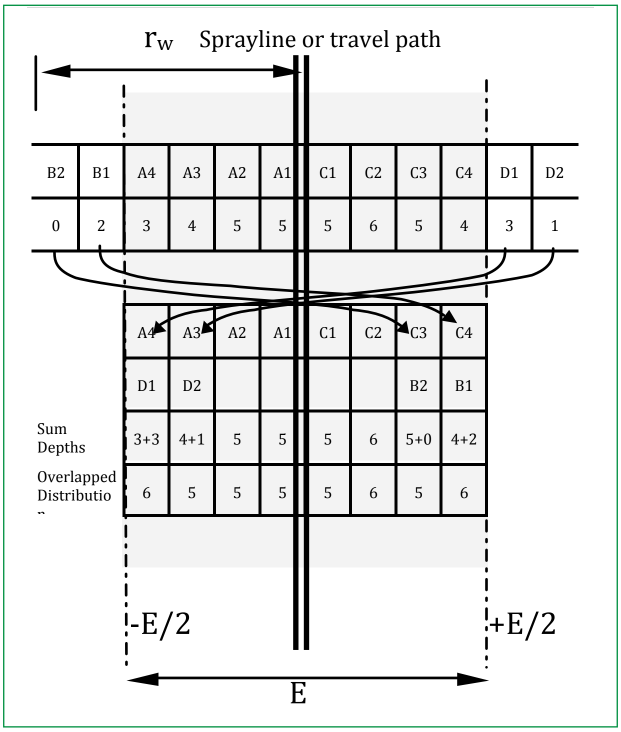

Fig. 2.1. Translation of out of strip data to wetting strip application depth estimates

2.3.2 ALTERNATE SETS

Where alternate sets are used, application depths must be adjusted to account for secondary overlap effects.

Repeat the overlay: overlay A4+D1 on to C1, A3+D2 on to C2, and A2 on to C3 etc as in (above).

2.4 Grid uniformity test

The grid uniformity test is used to assess distribution uniformity of sprayline systems where adjacent spraylines overlap.

1. Arrange a grid of collectors between three correctly functioning adjacent sprinklers along a representative part of the sprayline (Fig 4.3.1).
   - The grid must extend beyond the sprinkler wetted radius on both sides of the sprayline.
   - Define *collector columns* as the lines perpendicular to the sprayline and collector rows as the lines parallel to the sprayline.
   - The maximum spacing between collectors should be 3m for sprayers or 5.0m for spinners or rotators (ISO 11545).

Note: Ensure the spacing between collector columns (S_{cc}) is a factor of the sprinkler spacing (D_s).

   - E.g. If D_s = 10 m, S_{cc} = 2.0, 3.33, or 5.0m
   - Ensure the first and last columns of collectors are positioned one half column spacing from the first and last test sprinklers respectively.

Note: Ensure the distance between collector rows (S_{cr}) is a factor of half the wetted strip width (E).

   - E.g. If E = 20m, E/2 = 10m, S_{cr} = 2.0, 3.33 or 5.0m.
   - Ensure the first row of collectors is positioned one half column spacing from the first and last test sprinklers respectively.
   - The lines of collectors must extend to the full wetted radius of the water distribution system, allowing for any skewing as a result of wind effects.

2. Measure and record the position of each collector relative to the sprayline.

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