

Irrigation Code of Practice and Irrigation Design Standards

March 2007



Disclaimer:

This report has been prepared solely for the benefit of the New Zealand irrigation industry. No liability is accepted by Irrigation New Zealand or any employee or sub-consultant of this organisation with respect to its use by any other person.

This disclaimer shall apply notwithstanding that the report may be made available to other persons for an application for permission or approval or to fulfil a legal requirement.

TABLE OF CONTENTS

	Page
Foreword.....	1
Acknowledgements	1
1 Introduction	2
1.1 Background	2
1.2 Purpose of Standards.....	2
1.3 Context of Design Code of Practice.....	3
1.4 Legal Status of Code of Practice.....	3
1.4.1 Technical Standards and Guidelines	4
1.4.2 Certification.....	4
1.5 What is Not in the Code.....	4
1.6 How Should the Code of Practice be Used.....	4
2 Definitions	6
3 Key Performance Indicators (KPI's).....	9
4 Codes of Practice	12
4.1 Planning	12
4.1.1 Initial Preparation by Irrigator	12
4.1.2 Initial Contact by Client.....	13
4.1.3 Property Visit	13
4.2 Design	15
4.2.1 Water Source.....	15
4.2.2 Soil-Crop-Water Relationships	16
4.2.3 Irrigation Application Rates.....	17
4.2.4 Application Efficiency	18
4.2.5 Application Uniformity.....	19
4.2.6 Irrigation System Capacity.....	20
4.2.7 Irrigation System Selection.....	20
4.2.8 Sprinkler/Emitter Selection and Layout.....	21
4.2.9 Hydraulic Design	22
4.2.10 Pumps and Motors.....	23
4.2.11 Electrics.....	24
4.2.12 Control.....	24
4.2.13 Filtration.....	26
4.2.14 Back Flow Prevention.....	26
4.2.15 Measurement and Monitoring.....	27
4.3 Quoting and Supply	29
4.3.1 Supplier Information	29
4.3.2 Client Information.....	29
4.3.3 Design Specification	29
4.3.4 Technical Analysis	30
4.3.5 Technical Supporting Information	30
4.3.6 Bill of Materials	30
4.4 Installation.....	31

4.5	Commissioning	32
4.5.1	Commissioning Process	32
4.5.2	As-built Plan.....	32
4.5.3	Report.....	32
4.6	Operation and Maintenance	33
4.6.1	Operation and Maintenance Instructions	33
4.6.2	Servicing	33
4.6.3	Responsibilities of Dealer	33
4.6.4	Responsibilities of Purchaser	34
5	Design Standards.....	35
5.1	Planning	35
5.2	Design	35
5.2.1	Water Source.....	35
5.2.2	Soil-Crop-Water Relationships	35
5.2.3	Irrigation Application Rates.....	37
5.2.4	Application Uniformity.....	38
5.2.5	Application Efficiency (E_a).....	40
5.2.6	Irrigation Adequacy	41
5.2.7	Irrigation System Capacity (W)	42
5.2.8	Irrigation System Selection.....	44
5.2.9	Hydraulic Design	44
5.2.10	Pumps and Motors.....	46
5.2.11	Filtration.....	48
5.2.12	Measurement and Monitoring.....	50
5.3	Pump Suction Issues	50
5.3.1	Suction Lift.....	50
5.3.2	Cavitation	50
5.3.3	Net Positive Suction Head (NPSH).....	52
5.3.4	NPSH Margin.....	52
5.3.5	Measurement and Control	53
5.4	Pump Design and Installation	54
5.4.1	Surface Mounted Centrifugal Pumps	54
5.4.2	Submersible Pumps.....	56
5.4.3	Friction Loss Past Submersible Motors	56
5.5	Pump Electrics	57
5.5.1	Submersible Pumps.....	57
5.6	Control	57
5.6.1	Headworks.....	58
5.7	Measurement and Monitoring.....	60
5.8	Installation.....	60
5.9	Testing and Commissioning	60
6	Design Performance Table	62
7	References	63

List of Appendices:

Appendix A:	Abbreviations and symbols	64
-------------	---------------------------------	----

List of Tables:

Table 1: Performance indicators 9
 Table 2: Property visit 14
 Table 3: Estimated soil water holding capacity 35
 Table 4: Approximate crop root depths for mature crops 36
 Table 5: Allowable percentage soil moisture depletion 36
 Table 6: Estimated maximum allowable water application rates 37
 Table 7: Approximate soil intake curves 38
 Table 8: Recommended EU_{des} for microsprinkler and drip irrigation 38
 Table 9: Recommended CU_c 's and DU_{Iq} 's for various system types 39
 Table 10: Recommended minimum CU_c 's for various uses 40
 Table 11: Recommended sprinkler spacing as a percentage of wetted diameter 40
 Table 12: Approximate E_a for various irrigation methods 41
 Table 13: Crop coefficients based on pasture 43
 Table 14: Recommended maximum water velocities 45
 Table 15: Recommended minimum water velocities 45
 Table 16: Recommended safety factors for pump duties 46
 Table 17: Typical efficiencies for properly chosen centrifugal pumps 47
 Table 18: Classification of screens and particle sizes 49
 Table 19: Soil moisture measurement methods 54
 Table 20: Allowable suction velocities 55
 Table 21: Design summary 62

List of Figures:

Figure 1: Soil infiltration rates according to watering time 38
 Figure 2: Effective water use for a range of CU_c 's 42
 Figure 3: Motor efficiencies 47
 Figure 4: Part load motor efficiencies 48
 Figure 5: NPSH margin ratio 53

List of Equations:

Equation 1:	Potential soil moisture deficit (PSMD).....	66
Equation 2:	Seasonal potential soil moisture deficit (PSMD _{season}).....	66
Equation 3:	Seasonal deep percolation (SDP).....	66
Equation 4:	Seasonal irrigation deep percolation (SDP _i).....	66
Equation 5:	Drought induced yield loss (YL_{di}).....	66
Equation 6:	Value of lost yield (YL_v).....	67
Equation 7:	Irrigation requirement (IR).....	67
Equation 8:	Coefficient of variation (C_v).....	67
Equation 9:	Standard deviation from the mean (s).....	68
Equation 10:	Emitter pressure flow relationship.....	68
Equation 11:	Emitter discharge exponent.....	68
Equation 12:	Emitter discharge coefficient (K_d).....	68
Equation 13:	Manufacturer's emission uniformity (EU_{man}).....	69
Equation 14:	Distribution uniformity (DU_{lq}).....	69
Equation 15:	Christiansen coefficient (CU_c).....	69
Equation 16:	Emission uniformity (EU).....	70
Equation 17:	Emission vs Distribution uniformity.....	70
Equation 18:	Emitter emission uniformity (EEU_{lq}).....	70
Equation 19:	Design uniformity (EU_{des}).....	70
Equation 20:	Application Efficiency.....	71
Equation 21:	Total system application depth (D_{mf}).....	71
Equation 22:	Infiltration depth (drip-micro and long-lateral).....	71
Equation 23:	Equivalent applied depth (drip-micro).....	71
Equation 24:	Instantaneous application rate (R_{it}).....	71
Equation 25:	Instantaneous application rates – linear move (R_{il}).....	72
Equation 26:	Instantaneous application rates – centre-pivot (R_{ip}).....	72
Equation 27:	Well flow-drawdown relationship.....	72
Equation 28:	Hazen Williams formula.....	72

List of Units

d	day
h	hour
ha	hectare
km	kilometre
km/h	kilometre per hour
kPa	kilopascal
kW	kilowatt
kWh	kilowatt hour
ℓ	litres
ℓ/s/ha	litres per second per hectare
m	metre
mm	millimetre
m/s	metres per second
m ²	square metre
m ³	cubic metres
m ³ /h	cubic metres per hour
s	second
yr	year

FOREWORD

This code of practice provides guidance on the irrigation industry's expectation of acceptable levels of irrigation design to irrigation designers, irrigation owners and operators.

In some circumstances, practices or equipment other than those suggested in the Code may be equally relevant in meeting irrigation industry standards.

The Code is non-regulatory and essentially advisory, and not intended to encroach on any areas of legislative responsibility.

Irrigation New Zealand believes that if the Code is honestly maintained by the irrigation industry, designers will plan, install and provide the ability to operate irrigation systems in an economic and environmentally sustainable manner.

Irrigation New Zealand Chairman

ACKNOWLEDGEMENTS

Organisations, individuals and stakeholders contributing to the preparation of this Code of Practice include:

- Irrigation New Zealand
- Parkland Products Ltd– Peter Gant
- HydroServices Ltd – Tony Davoren
- Bloomer & Associates – Dan Bloomer
- Water Dynamics Ltd – Steve McNally
- Fruitfed Ltd – Dan Norman
- Aqualinc Research Ltd – Ian McIndoe
- Ron Dalley

and individuals, farmers, and staff from irrigation design and supply companies in New Zealand, who willingly provided advice.

Financial support for preparation of the Code has been provided by:

- Ministry of Agriculture & Forestry (Sustainable Farming Fund)
- Irrigation New Zealand
- Northland Regional Council
- Hawkes Bay Regional Council
- Southland Regional Council
- Tasman District Council
- Taranaki Regional Council
- Environment Waikato

1 INTRODUCTION

1.1 Background

Rapid irrigation development has taken place in New Zealand, particularly towards the end of the 20th century, with increasing levels of investment in irrigation systems and irrigation research being made. In general, irrigation has been highly successful and has driven agricultural expansion in the drier areas, improving and sustaining the general well-being of rural communities – something that would not have been possible without irrigation. However, some irrigation systems have under-performed in economic terms, and independent irrigation audits have highlighted shortcomings in irrigation system design and management. Reasons for this include:

- Unrealistic expectations by the owners at the system appraisal stage;
- Capital cost over-runs;
- Substandard design and installation;
- Poor irrigation system management and service provisions; and
- Poor understanding of client priorities and needs.

In addition, water regulators (regional councils), government agencies, the agricultural community and the general public have become more aware of potential adverse effects of irrigation on water quantity and quality. Increasing pressure is being placed on irrigation owners to lift the level of economic and environmental performance.

The cost of irrigation system failures can be high, with significant production and economic consequences. Environmental failures due to irrigation systems could also have very detrimental effects on the sustainability of irrigated agriculture. Poor environmental performance could lead to loss of water supply. Failure to demonstrate environmental responsibility could lead to loss of local and international markets for produce.

There are no performance standards or codes of practice for irrigation system design in New Zealand. Irrigation New Zealand, as part of its charter to promote economically and environmentally sustainable irrigation, has taken a proactive step and initiated the development of irrigation system design performance standards and a code of practice. Development of the code has been financially supported by MAF Sustainable Farming Fund (Grant 02-079).

1.2 Purpose of Standards

Irrigation New Zealand's goal is efficient and sustainable use of water, energy, labour and capital in irrigation systems in New Zealand. Four key developments contribute to achieving this goal:

- 1) Key performance indicators (KPI's) for irrigation systems and minimum acceptable standards for the KPI's;
- 2) An Irrigation Design Code of Practice, that, with the KPI's, describes the minimum acceptable design practices for the irrigation industry;
- 3) An industry recognised designer certification programme; and

- 4) NZQA recognised unit standards for the training of irrigation designers to the standard required to achieve the standing of Certified Irrigation Designer.

An irrigation system design completed in compliance with the Irrigation Design Code of Practice will, among other things:

- Explicitly state what KPI values will be achieved using this design, if the specified equipment is installed correctly; and
- Give sufficient details on what to measure and where, throughout the irrigation system, for the purchaser or a third party to verify that the system is achieving the KPI values.

1.3 Context of Design Code of Practice

The Irrigation Design Code of Practice describes the procedures that irrigation designers must follow to meet the required performance standards.

It uses the KPI's to focus the design process (planning, design, implementation and operation of an irrigation system) on outcomes that will meet a specified level of performance.

The irrigation design plan will specify the level of performance expected for a design, expressed in terms of the KPI's.

To determine whether the performance standards have been met, an evaluation process will be required, to compare the specified design performance standards with the values actually achieved in the field. This evaluation process will measure outputs to enable the actual KPI's to be calculated.

Without tools to assess actual system performance, irrigators and other stakeholders are not able to determine or benchmark performance.

In parallel to the Design Code of Practice, a Code of Practice for On-Site Irrigation Evaluation (Bloomer, 2006) has been developed to provide guidelines for irrigators and others undertaking evaluations of irrigation systems in the field. It makes recommendations for planning and conducting evaluations and reporting on the performance of irrigation systems and their management.

The Evaluation Code has been developed with reference to the *NZ Code of Practice for Irrigation Design*, international practices and standards. The main aim of the guidelines is to encourage adoption of standardised evaluation practices that are cost-effective, recommendation-driven and encourage more efficient use of irrigation resources. Its focus is on water application efficiency, but other key performance indicators are addressed.

1.4 Legal Status of Code of Practice

The Code of Practice does not, at this time, carry any legal status. Its development has been led by Irrigation New Zealand, with input and support from irrigation

experts and the irrigation industry. Its adoption and implementation are voluntary. It recognises the need for designers to interpret the guidelines according to individual requirements, provided these decisions comply with legal requirements, regulations and industry standards. These decisions should also comply with principles of preserving natural resources.

1.4.1 Technical Standards and Guidelines

Standards and guidelines from other Codes of Practice that are referenced within the Code are overseen by the relevant issuing authority.

The International Organisation for Standardisation (ISO) has responsibility for the International Standards published under its name.

1.4.2 Certification

A certified irrigation design training programme will be made available to irrigation designers in New Zealand. This NZQA-registered programme will enable designers to attend irrigation design courses and formally recognise those that meet the unit standards with the industry-recognised title “Certified Irrigation Designer”. The training programme will help irrigation designers to comply with the Irrigation Design Code of Practice by providing them with the understanding and tools required to achieve the required standards.

1.5 What is Not in the Code

This Code applies only to the design of irrigation systems. It does not cover irrigation equipment manufacturing or quality standards. Those activities should be guided by the relevant existing standards.

1.6 How Should the Code of Practice be Used

The Code of Practice includes standards that designers must aim to achieve, why they must achieve them, and when, where and how they should be achieved. Specific technical data is provided to help in this respect.

The KPI’s are listed so that designers are very clear about what is required and what will be measured once the design is installed and operating. Some of the indicators relate directly to design, others to a combination of design and operation.

The *Codes of Practice* section (Section 4) includes the design process section, provides general design approaches, and what should and should not be done.

The *Design Standards* section (Section 5) is grouped into relevant sections to make it easy for designers to look up a specific standard without going through the whole document. The standards have specific statements such as “*mainline velocities should not exceed 1.5 m/s in closed systems and 2.0 m/s in open systems*”.

The *Design Performance* Table 21 (Section 6) lists the output ranges expected from the design so that:

- Designers have a structured set of outputs on which to base their designs;
- Purchasers know what performance their system is supposed to deliver; and
- The relevant indicators can be calculated during a design evaluation.

Designers will follow the general design process (most will have their own procedures), using the standards to help them design the system, and will have clear instructions on outputs.

It is important that where a design does not meet the output range for a particular standard, the purchasers are informed and reasons given.

As far as possible, the expected standards have real, achievable and measurable, or assessable limits.

2 DEFINITIONS

For the purposes of this document, the following definitions shall apply:

Adequacy of irrigation: A measure of the proportion of the target area for which the soil is restored to a level that equals or exceeds a set level, or target soil water content.

Application depth: The mean application depth (mm) applied by an irrigation event during periods of peak irrigation demand. In some applications, such as for annual crops, the system may be required to meet a range of application depths to match progressive stages of crop development.

Application efficiency: The percentage of applied water that is retained in the root zone, or in the target area, after an irrigation event.

Application rate: The mean precipitation rate of the irrigation system, expressed in millimetres depth of water applied per hour.

Application uniformity: The spatial variability of application, defined in a variety of ways; the most common being distribution uniformity (DU), coefficient of uniformity (CU) and emission uniformity (EU).

Available water holding capacity: The difference in moisture content between field capacity and permanent wilting point, expressed in millimetres depth of water over a specified depth of soil (usually equal to the expected effective root depth of a crop during periods of maximum water demand). Dan Bloomer thinks this should be volumetric, mm water held/100mm soil. I'd like to use Total Available Water to be the AWHC in the effective root zone. (I think)

Back flow preventer: A device or devices installed in a pipeline to prevent water flowing in reverse through the system.

Capital cost: The overall system purchase and installation cost (\$) or cost per unit area (\$/ha) as total or annualised cost. For the purposes of economic analysis, annualised capital cost may also be expressed as cost per unit volume (\$/m³) based on mean annual irrigation demand.

Crop factor: The ratio of the water requirements of a particular crop to that of a reference crop (usually average grass pasture).

Design area: The specific land area in hectares, which the supplier (or designer) and the irrigation system purchaser mutually understand is to be irrigated by the irrigation system.

Design system capacity: The mean daily flow of water per hectare of irrigated area used in the design of the system

Distribution efficiency: A measure of how much of the water supplied to the Property reaches the application system. It is a function of losses incurred in the conveyance or distribution system, from the point of water abstraction or entry to the Property (in the case of irrigation schemes) to the application system.

Drainage depth: The potential drainage volume based on peak irrigation demand. This is typically expressed as volume per unit area (m^3/ha) or an equivalent depth per unit area (mm/ha).

Effective root depth: The depth of soil profile that has enough rooting density for extraction of available water, if needed. Roots may be found at depths greater than this value but do not contribute significantly to water extraction.

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, 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.

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 rate at which the soil can absorb water, which changes according to the wetness of the soil. Infiltration rate is usually expressed in units of mm/hour .

Irrigation system: This comprises all of the equipment required to transfer water from the water source to the crops in the design area.

Leaching: Deep percolation of water beyond the root zone of plants, resulting in loss of salts or nutrients.

Mainline: A pipeline in a pressurised distribution system that transports water from the water source to sub units or zone control valve in a system.

Management allowable deficit (MAD): The percentage of available water that is accepted to be depleted before irrigation is required. Often known as stress point or critical deficit.

Operating system capacity: The mean daily flow of water per hectare the system is able to provide the way it is being managed

Permanent wilting point: The soil moisture content at which a plant will die from drought stress. For practical purposes, it is the soil water content at a soil tension of 15 bar (1500 kPa).

Potential system capacity: The mean daily flow of water per hectare the system is able to provide in the time available.

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.

Readily available water holding capacity: The difference in moisture content between field capacity and the stress point (equal to a soil suction of 200-500 kPa), expressed in millimetres depth of water over a specified depth of soil (usually equal to the expected effective root depth of a crop during periods of maximum water demand).

Readily system capacity: The mean daily flow of water per hectare required to meet the demands of the crop at Peak ET after accounting for the duration that water is available.

Return interval: The interval between successive irrigation cycles during periods of peak demand and no rainfall.

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 \$/m³). Values can be positive or negative, dependent on system costs, productivity and crop returns.

Scheduling coefficient: A ratio to indicate how much additional water above the mean application needs to be applied to adequately overcome non-uniform applications.

Surface runoff: An assessment of the potential surface runoff (volumetric) proportion from the system operating during periods of peak irrigation demand. Generally, such considerations are limited to surface irrigation systems and some spray systems.

System capacity: A measure to assess the ability of a system to meet total system requirements; crop irrigation demand and losses due to non-uniformity of application and distribution losses.

Uniformity coefficient (Christiansens): A measure that defines the variability of individual application depths from the mean and, therefore, the impact of overall uniformity. It has most commonly been used in the description of sprinkler application uniformity, but can be equally useful in defining field and system uniformity.

Water holding capacity: The maximum amount of water that can be held in the soils that is available for plant growth. For practical purposes, it is the difference between field capacity and permanent wilting point.

3 KEY PERFORMANCE INDICATORS (KPI'S)

The ultimate performance of an irrigation system is dependent on the design and management of that system. System design establishes the key system performance characteristics, and management enables the fulfilment of these characteristics.

In the case of irrigation system design, KPI's have been selected to provide a measure of not only system performance but also effects and impacts on the environment, economics, productivity and labour. They provide both irrigators and designers with a quantifiable measure of the system, for comparison with industry benchmarks and between systems and system types.

The KPI's are grouped into six areas of measurable performance, as described in Table 1 as follows:

- a) Water use efficiency
- b) Energy use
- c) Labour
- d) Capital
- e) System effectiveness
- f) Environment

Irrigation designers, to comply with the Code of Practice, will, in the design report or quotation provided to the system purchaser:

- Explicitly state what KPI values will be achieved using this design, if the specified equipment is installed correctly; and
- Give sufficient details on what to measure and where, throughout the irrigation system, for the purchaser or a third party to verify that the system is achieving the KPI values.

For most indicators, specific base information needs to be available, or measured, to allow the indicators to be calculated. In addition to the KPI values themselves, the information used to calculate the indicators as described in the associated information in Table 1 or the assumptions made in calculating the indicators must also be provided to the purchaser.

Table 1: Performance indicators

Key performance indicator	Unit(s)	Associated information
<i>Water Use Efficiency</i>		
Irrigation crop demand	mm/d m ³ /ha/week mm/hr (frost)	<ul style="list-style-type: none"> – Crop type, crop factors, soil type – Climate (rainfall and evapotranspiration) – Level of risk of not meeting soil water deficits
System capacity (based on 24 hours)	ℓ/s/ha mm/day	<ul style="list-style-type: none"> – Flow rate of irrigation system – Irrigated area – Actual hours of pumping per day

Key performance indicator	Unit(s)	Associated information
Management allowable deficit (MAD)	mm %	<ul style="list-style-type: none"> – Soil water holding capacity in root zone during peak design period – % of available water that is accepted to be depleted before recharge (irrigation) is required
Application depth	mm	<ul style="list-style-type: none"> – Gross depth of water applied
Return interval	days hours	<ul style="list-style-type: none"> – For larger systems – For some micro/turf systems
Application rate	mm/hr	<ul style="list-style-type: none"> – Gross depth of water applied – Time (hours) taken to apply water
Infiltration rate	mm/hr	<ul style="list-style-type: none"> – Soil infiltration rate characteristics – Slope – Crop cover – Time to apply water
Application uniformity	% ratio	<ul style="list-style-type: none"> – CU – DU, SC
Adequacy of irrigation		<ul style="list-style-type: none"> – The ratio of the mean low quarter depth applied, to the mean target depth required across the field as a whole.
Potential application efficiency	%	<ul style="list-style-type: none"> – The single event potential application efficiency is estimated from field distribution uniformity and surface losses due to runoff and leakages.
Distribution efficiency	%	<ul style="list-style-type: none"> – Water supplied to the property – Water discharged from application system
Headwork efficiency	%	<ul style="list-style-type: none"> – Pressure loss through headworks components net of elevation differences
Supply reliability	days	<ul style="list-style-type: none"> – The number of days when supplies will not be available in a 1:5 or a 1: 10 year drought
<i>Energy Use Efficiency</i>		
System energy rating	kW	<ul style="list-style-type: none"> – Size of pumps in kW
System pumping efficiency	%	<ul style="list-style-type: none"> – Energy consumed to (volume of water moved and pressure increase)
Energy per unit volume	kWh/m ³ (based on meter readings)	<ul style="list-style-type: none"> – Seasonal volume of water pumped – Seasonal kWh of energy used
<i>Labour Efficiency</i>		
Hours per hectare per year used for operation	hr/ha	<ul style="list-style-type: none"> – Time spend on operating irrigation system – Effective area irrigated
Hours per hectare per year used for maintenance	hr/ha	<ul style="list-style-type: none"> – Time spend on maintaining irrigation system – Effective area irrigated
Hours per mm applied	hr/mm	<ul style="list-style-type: none"> – Time spend on operating and maintaining irrigation system – Seasonal depth of water applied
<i>Capital Efficiency</i>		

Key performance indicator	Unit(s)	Associated information
Capital cost per hectare	\$/ha	<ul style="list-style-type: none"> – Total cost of irrigation system – Effective area irrigated
Operating cost/volume applied	\$/mm/ha \$/ML	<ul style="list-style-type: none"> – All running costs of irrigation system – Effective area irrigated – Effective depth of water applied
Annual operating cost per hectare	\$/ha	<ul style="list-style-type: none"> – All running costs of irrigation system – Effective area irrigated
Total annual cost per hectare	\$/ha	<ul style="list-style-type: none"> – Capital cost per hectare – Annual cost per hectare – Cost of finance (rate, term)
<i>Environmental Performance</i>		
Average system efficiency	%	<ul style="list-style-type: none"> – Water supplied to the property – Water beneficially used
Drainage index	m ³ /ha/yr	<ul style="list-style-type: none"> – Volume of water draining through profile – Area irrigated (ha)
Redistribution index	m ³ /ha/yr	<ul style="list-style-type: none"> – Volume of water reaching target area – Total volume of water applied

Explanation of the components forming these indicators is given in the *Definitions* section (Section 2).

Although most of the KPI's are generic in that they apply to all types of irrigation systems, some are not. Where they apply, they should be included. Where they don't, they can be left out.

For convenience, an electronic copy of the indicators table is available from Irrigation New Zealand.

4 CODES OF PRACTICE

The design process can be conveniently divided into five key components:

- a) Planning
- b) Design
- c) Quoting Agreement, Warrantees and Supply
- d) Installation and Commissioning
- e) Operation and Maintenance, Maintenance Retentions

In the *Planning* stage, the needs of the purchaser and any issues that need to be considered before significant resources are committed to the project are determined.

In the first part of the *Design* process, specifications and levels of performance are determined. Design then involves selecting appropriate components and determining how they should be assembled to deliver and apply water in a way that meets the design specifications.

Quoting and Supply involves providing a purchaser with the necessary documentation including the performance (KPI's) of the system to be supplied.

Installation and Commissioning covers construction of the irrigation system and testing to ensure that it operates to specification. Commissioning should also include instruction and training of the irrigation system operators.

Operation and Maintenance is primarily the owner's responsibility, but needs to be considered at the design stage.

Although the design process has been simplified into five steps, the process is an interactive one, involving purchasers, designers, suppliers and operators.

4.1 Planning

4.1.1 Initial Preparation by Irrigator

The first step for an irrigator in developing or upgrading an irrigation system is to carry out an initial investigation in sufficient detail so that initial decisions involving commitment of capital and other resources can be justified.

In addition to legal, regulatory, financial and economic analyses, the initial investigation should consider the following:

- The likely availability of a water supply;
- Information to support water consent applications;
- Compliance with any regulatory requirements;
- Deal with any issues related to intensification of land use;
- An economic analysis (usually carried out by an independent advisor);
- Information to support applications to financiers;
- An assessment of human resource issues; and
- Details required by the designer of the irrigation system.

From a design perspective, it is important that enough detail is included to provide accurate information to the system designer so that a water efficient and economically feasible design can be prepared that is suitable for the crops to be irrigated in the planned location.

This preparation would be expected to be carried out prior to a prospective irrigator approaching an irrigation firm for a design and quote. However, it is possible for irrigation firms to be approached by potential purchasers to obtain a rough price for budgetary purposes without going through the design process in full.

4.1.2 Initial Contact by Client

The client or client's representative will normally approach an irrigation firm to initiate the design and supply of an irrigation system.

The irrigation firm's representative should:

- Establish the client's needs;
- Offer suggestions in general about how to irrigate the property;
- Find out if the necessary water consents and other legal requirements can be or are likely to be met – if they have not been met, advise them on how to go about obtaining the necessary consents;
- Explain the terms and conditions of any agreements that might be made, including costs for investigation and design, should purchase and installation not proceed; and
- If the client wishes to progress the investigation, arrange for a time to meet on the property.

The irrigation firm should not:

- Promise something that cannot be delivered;
- Attempt to sell a system that clearly will not meet the needs of the client; or
- Offer to design an irrigation system without visiting the property unless it is certain that there will be no outstanding issues that could have been resolved with a property visit.

4.1.3 Property Visit

Having obtained sufficient information from the client to ensure that further investigation is warranted, the property should be visited so that the details necessary for design to be completed can be obtained.

The following should be discussed and the necessary information obtained:

Table 2: Property visit

Item	Description
Property layout/shape	Fixed boundaries, permanent features, roads, other obstructions.
Map	Can a copy of a property map be obtained?
Design area	What area is intended to be irrigated? Is there a priority?
Elevation	Elevations, slope, hills, gulleys, flood risk.
Topography	Trees, streams, water races, buildings, power pylons, obstructions.
Land restrictions	Protected areas, covenants on titles.
Shelter	What natural or artificial wind breaks will be present or required?
Animals	What and how many stock will be grazed in the irrigated area?
Fencing	What fencing arrangement will be used, how will it affect shifting?
Water supply location	Is it fixed, or will it be determined in the design?
Water quantity	What is available or approximately what will be required?
Water supply reliability	What restrictions could the supply be subjected to? Is storage needed?
Water quality/chemistry	Is the quality physically and chemically suitable for the proposed irrigation system?
Soil water holding capacity	What are the soil type, plant available water and readily available water?
Soil infiltration capacity	How quickly will the soil absorb water? Are there any soil pans? Is soil erosion likely to be a problem?
Drainage	Potential drainage problems.
Crops	What crops are to be grown short-term and long-term?
Contracts	What conditions do crop contracts impose with respect to irrigation?
Other needs	Is water required for other purposes (e.g. germination, fruit cooling, frost, leaching of salts)?
Risk preference	How much risk of not meeting demand is the client prepared to accept?
Rainfall	Are rainfall records available? If not, where is the nearest record?
Evapotranspiration	Where is the nearest record?
Wind	Where is the prevailing wind? When does it blow, and at what strength?
System catchup ability	What requirements for “catching up” after restrictions will be needed?
Energy source	If power is required, where is it going to come from? What supply limitations are there?
Future flexibility	Is there a need to consider a future change in method?
Labour	What labour and skill level is available to operate the system?
Health & safety	What health and safety issues could arise?
Price limits	How much money is the client prepared to spend and how?

Item	Description
Delivery	When does the system have to be operational?
Personal preferences	Does the client have any personal preferences for systems?
Restrictions	Are there any restrictions regarding installing and operating the system (e.g. dependence on subcontractors)?
RMA	Have the necessary consents been obtained and under what conditions?
Special conditions	Are there any special conditions relating to the taking and using of water?
Vandalism	What is the likelihood of vandalism?
Other	Any other issues relevant to the client?

The irrigation dealer's representative should:

- Deal with the client in a friendly and professional manner; and
- Guide the client where necessary.

The irrigation firm must not:

- Force or coerce the client into making decisions; nor
- Attempt to sell a system that clearly will not meet the needs of the client.

4.2 Design

4.2.1 Water Source

General requirements

Without a reliable water source, an irrigation system is worthless; yet many irrigation systems are designed, purchased and installed without water being available. Often, water is available. However, in an increasing number of cases, water cannot be obtained, or is subject to significant delays (sometimes for years).

Irrigation suppliers and designers must not knowingly sell an irrigation system to a client where obtaining a supply of water is at risk unless the risk and the circumstances relating to the supply are clearly known or explained to the purchaser.

Ultimately, it is the purchaser's decision as to whether or not to proceed, assuming a water source is confirmed. The purchaser must be given the necessary information, or given guidance on how to obtain that information, to make an informed decision.

RMA issues – consent conditions

Irrigation designers and suppliers must:

- Be familiar with regional council and local council requirements with respect to irrigation.
- Where water permits have been obtained, obtain a copy of the permit and ensure that the relevant necessary equipment is supplied and installed so that the purchaser can meet the terms of the consent conditions.

- Explain to the purchaser what is required to meet the conditions of consent.
- Where water permits have not been obtained but will be in the future, explain to purchasers what is normally required to meet conditions of consent and include the relevant equipment in quotes or cost estimates.

Purchasers should ensure that all relevant information regarding consents and conditions is provided to designers.

Water access issues

Any issues related to access to water must be determined and communicated between the designer, client and potentially affected parties. Any uncertainties in gaining access to water and any requirements for gaining access (such as easements) must be discussed.

In the case of groundwater, factors to be considered include (but are not limited to) consenting issues, consent conditions, bore location, bore diameter, well driller availability and likely yield.

For surface water takes, factors to be considered include location of intake and access, intake design, method of conveyance (e.g. canals, pipes) and turnout design. If water is from a community scheme supply, access and cost of water, and any specific scheme requirements must be considered.

Quantity of water physically available

The quantity of water available will, in many cases, be limited for some or all of the time. This may be due to yields for bores, scheme or regulatory restrictions, flows in streams and water stored in dams, for example.

Water supply may also be subject to seasonal restrictions, whether they are due to changing stream flows or changing groundwater levels. Due account should be taken of possible changes in water availability or restrictions in determining irrigation system capacities, irrigation components, area irrigated and risk of shortfalls. It may be necessary to increase overall system capacity to provide a ‘catchup’ ability to minimise the effect of shortfalls or build in extra capacity in pumps to lift water from greater depths.

Water supply reliability must be determined, any alternatives considered, and reasons for selection given.

4.2.2 Soil-Crop-Water Relationships

When choosing and designing an irrigation system, designers should obtain the necessary soil and crop data to ensure that the irrigation system can be designed to match appropriate soil-crop conditions.

Soil water holding capacity (AWHC)

To determine soil water holding capacities:

- Obtain local expert advice from someone who has specific knowledge about the soils on the property; or

- Refer to GIS soil maps or other soil maps of the region; or
- Take soil samples and measure water holding capacities (standard techniques such as oven drying can be used); or
- If no specific information is available, use Table 3 on Page 35.

Ensure that the depth of soil over which water holding capacity has been determined is known and adjusted for effective crop rooting depths.

Effective crop root depths

To determine crop rooting depth:

- Obtain local expert advice from the property owner or someone who has specific knowledge about rooting depths of crops on the property; or
- Dig a hole and observe crop rooting depths. If no specific information is available, use Table 4 on Page 36.

Allowable depletion

To determine allowable depletion of soil moisture:

- Obtain local expert advice from someone who has specific knowledge about crop needs; or
- Use Table 5 on Page 36; or
- Use 50%.

Net application depth

Desired application depths depend primarily on water holding capacities and crop rooting depths. A range of application depths should be specified for different soil and crop types so that an irrigation system capable of meeting the needs of the crop is selected. The extent to which the client can vary the depth of water applied will depend primarily on the irrigation system type.

The designer should:

- Determine the maximum and minimum depths of water required to satisfy crop needs, while maintaining efficient irrigation practices;
- Provide a summary of those needs, preferably in table format;
- Include on the table the depths of water that the irrigation system is capable of applying; and
- Explain what measures or changes to the system are required to achieve those application depths (e.g. changing run times, changing nozzles, etc.).

4.2.3 Irrigation Application Rates

Application rate refers to the rate (intensity) at which water is applied to the soil by the irrigation system. Infiltration rate refers to the rate at which the soil can absorb water. Infiltration rate changes according to the wetness of the soil. Both application rate and infiltration rate are usually expressed in units of millimetres per hour (mm/hour).

Ideally, irrigation systems should be selected so that the average application rate of the system does not exceed the infiltration rate of the soil. However, because this is

difficult to achieve in many circumstances, designers should identify when application rate is likely to exceed infiltration rate and explain the consequences of it happening.

Soil infiltration rates

Be aware that soil infiltration rates change over time. The infiltration rates of well-structured irrigated soils may be considerably higher than on previously unirrigated soils of similar types. Designers should consider appropriate soil infiltration rates by:

- Obtaining local expert advice from someone who has specific knowledge about the soil infiltration rates on the property; or
- Referring to information sources detailing soil infiltration rate properties; or
- Carrying out soil infiltration rate tests on the property; or
- Use Table 6 (or Figure 1, Page 38) and Table 7 on Page 37 and Page 38, respectively.

Spray irrigation application rates

In spray irrigation systems, application rate is governed by the flow rate and wetted coverage of the sprinklers. It must take into account the overlapping patterns of sprinklers. Average application rates for spray irrigation systems are relatively easy to measure or calculate. Designers should make these calculations, as follows:

- For centre-pivots, at 2/3rds radius and at the centre of the outmost (last) span;
- For rotating booms or guns, the average over the wetted circle or part thereof based on effective radius;
- At the effective radius (usually half of the lane spacing) of the boom or gun;
- For travelling booms, or linear moves with overlapping sprinklers, at an undisturbed location along the boom; and
- For sprinklers operating in a fixed grid, with acceptable overlap formulae.

Stream impact energy

The breakdown of soil particles at the soil surface is mainly relevant to high-volume sprinkler irrigation. This is caused by the impact of the irrigation water on the soil particles causing either movement of the particles or the breakdown of the soil into smaller particles.

To reduce problems with soil breakdown and movement, it may be necessary to avoid using particular types of irrigation systems. Designers should:

- Identify potential problems with stream impact energy;
- Select an irrigation system type to minimise or eliminate problems with stream impact; and
- If potentially a problem, make it known to the purchaser of the irrigation system.

4.2.4 Application Efficiency

Application efficiency depends on three main factors. These are:

- Applying the correct depth of water;
- Uniformity of application; and
- The rate at which water is applied to the soil.

Application efficiency is defined as the percentage of water retained in the soil in the root zone of a crop, compared to the average gross depth of water applied to the crop.

The irrigation system shall be designed to have the ability to meet an agreed level of application efficiency. The designer must provide the client with a system that has the potential to operate at the agreed level of application efficiency. Particular attention must be given to:

- Soil water holding capacity in the crop root zone;
- Allowable soil moisture deficits (stress points);
- Gross application depths;
- Return intervals;
- Application rates/soil infiltration rates; and
- Uniformity of application.

4.2.5 Application Uniformity

Even with irrigation systems capable of applying the desired depth of irrigation at the required rate, there are significant opportunities for inefficiencies through not applying water evenly. Poor application uniformity can be one of the main reasons for surface redistribution and losses to drainage.

The reasons for poor uniformity of sprinkler irrigation systems include:

- Poor or unsuitable sprinkler distribution patterns;
- Incorrect spacing of sprinklers;
- Component manufacturing variations;
- Wrong operating pressures of sprinklers;
- Pressure variations in the system; and
- The effect of wind on the sprinkler patterns.

The effects of poor uniformity may be difficult to detect with any of the indicators proposed. In extreme cases, reductions in yield become apparent in underwatered areas. However, detecting overwatering due to poor uniformity, especially if average application depths and application rates are correct, is problematic.

Use estimates of drainage (deep percolation) and potential soil moisture deficit based on DU values and target depths to calculate potential overwatering.

Wind

Sprinkler irrigation systems are often affected by wind blowing water from the irrigated area, or irrigators/sprinklers throwing water outside the irrigated area. Wind losses may be reduced by not irrigating in excessively windy conditions, or selecting an irrigation type that is less affected by the wind. Watering rectangular fields with circular application patterns most often causes watering outside of irrigated areas. To reduce or prevent this, control of the pattern is required (by using part circle sprinklers, for example), or some areas of the field (such as the corners) may need to be left unwatered. The design should take into consideration the frequency and direction of prevailing wind in orientation and spacing of emitters.

Use manufacturers recommendations for sprinkler spacing. If they are not available, refer to Table 11 (page 40).

4.2.6 Irrigation System Capacity

Unless otherwise agreed with the purchaser, the irrigation system shall have the capacity to meet the peak water demands of each and all crops irrigated within the design area, in terms of location, depth and frequency of irrigation. For affordability, the peak demand will normally be based on a likely frequency of demand (i.e. 1-in-10-year mean 7-day demand) rather than an absolute maximum value.

The exceptions are where irrigation is designed to meet lower than peak demand for reasons of water availability, crop quality or for specific economic benefits.

Sufficient time must be allowed for moving irrigation equipment and for integrating with normal day-to-day operations. The system capacity shall also allow for agreed water losses when the system is operated in accordance with the design specifications.

The system capacity should be determined and quantified from the following factors:

- Climate – rainfall and evapotranspiration;
- Crop factors;
- Crop demand;
- Level of risk client is prepared to take in not meeting demand;
- Hours of operation per day, and
- Water availability.

The capacity of the system must be discussed and agreed with the client. If a system is designed at a lower than normal capacity, the reasons for the lower capacity and the consequences of lower capacity must be explained to the purchaser.

4.2.7 Irrigation System Selection

Purchasers of irrigation systems have a range of expectations of an irrigation system. These include:

- Acceptable capital cost;
- Acceptable energy cost;
- Acceptable labour requirements;
- Acceptable public perception;
- Highly efficient water application;
- Idiot proof – easy to operate;
- Reliable, with low maintenance; and
- Grows maximum amount of quality crop/pasture.

Although designers should make it clear to purchasers that there is no perfect irrigation system, it is important that the selected system is suitable for the farming enterprise type and client need, and that the choice is justified. The purpose is to prevent inappropriate system types being sold to clients when there is doubt that they will deliver the expected performance.

The performance of the system and how well it meets the crop and enterprise needs as described above must be provided.

In general terms, actual performance includes items such as depths, return intervals, application rates, operating hours per day, overall system capacity, system uniformity, and so on. These are to some extent described in the indicators given in Table 1 (page 9). If actual performance is significantly different from assessed need, an explanation will have to be made and the consequences of the differences between assessed need and proposed system performance explained to the purchaser.

For example, high application rates at the ends of centre-pivots may cause surface redistribution and runoff, which will reduce application efficiency. The significance of that should be explained to the purchaser, ideally in terms of production. The approximate cost of reducing application rates and the expected benefits should be estimated.

General layout

In conceptual terms, one of the key factors is to design the property around the irrigation system, not the irrigation system around the existing internal property layout. This may mean moving fences, removing shelter belts or trees, and perhaps changing the position of drains or water races, or putting in new access-ways. Irrigation should take priority as it is a long-term investment. Structures are only shifted once; an irrigator may be shifted every day during the irrigation season and for many years.

The design and choice of irrigation system should take into account constraints, including:

- Topography of property;
- Human resources to operate the system efficiently and correctly;
- Environment of the property, such as the proximity to towns and presence of native vegetation and habitat;
- Water supply characteristics – quality, quantity, frequency and security;
- Occupational health and safety issues;
- Legal and regulatory requirements of the irrigation system, including all conditions related to taking and using water;
- Expansion strategy;
- System flexibility;
- Automation;
- Capital and ongoing annual costs required to build, operate and maintain the system selected; and
- Cost comparison with other alternative solutions.

4.2.8 Sprinkler/Emitter Selection and Layout

The method of water application must be suited to soil types, crop types and climatic conditions. The irrigated area must be suitable for a particular irrigation method based on the characteristics of the land, expected operating conditions and the requirements of the system operators.

Sprinklers should be selected and spaced for optimum uniformity of water distribution. System design and field management should complement each other to obtain best results. A combination of sprinkler spacing, nozzle size and operating pressure shall be selected to provide the desired application rates and uniformity.

Manufacturer's coefficient of uniformity (CU) or distribution uniformity (DU) data should be used to select the optimum sprinkler type, spacing, nozzle size and operating pressure ranges.

If manufacturer's CU or DU data is not available for the required sprinkler spacing and operating pressure, designers should determine CU and DU using appropriate sprinkler overlap software or formulae, if sprinkler profile data is available.

If suitable sprinkler profile data is not available, recommended sprinkler spacings given in Table 11 (page 40) should be used.

Designers should:

- Use single jet sprinklers in preference to twin jet sprinklers for windy areas (average wind speed >10 km/h);
- Design for lower operating pressure and larger droplets in windy conditions;
- Keep sprinkler operating pressures within manufacturer's recommended pressure ranges to prevent misting at high pressures and poor distribution at low pressures;
- Incorporate elevation variations into the calculations of sprinkler pressures where elevation changes exceed 5% of sprinkler operating pressure within a system subunit;
- Only use pressure compensating devices on sprinklers or emitters where it is impractical or uneconomic to design the system without pressure compensation;
- Take water quality issues into account when selecting suitable emitters or sprinklers for a design;
- If practical, design systems so that sprinkler laterals or lines are oriented so that prevailing winds flow across them;
- Travelling irrigators and linear move systems should preferably be designed to operate in straight rows;
- Design for larger application depths, low application rates and less shifts with labour intensive systems (subject to soil suitability) and smaller application depths, higher application rates and more shifts on automated systems; and
- Use smaller, more closely spaced nozzles whenever practical.

4.2.9 Hydraulic Design

Pipelines

The design of pipelines should take into consideration the following:

- Friction losses;
- Flow velocities;
- Soil conditions for buried pipelines;
- Environmental conditions for surface pipelines;

- Scheme or pipeline longevity;
- Capital costs; and
- System operating costs.

The pipeline design, in addition to friction loss analysis, may also consist of (where relevant) economic analysis, which includes pumping and operating costs for investment optimisation.

Open channel design

If open races are used to supply water to irrigation systems, best design practice by qualified engineers must be carried out. Key factors in design of channels should consider at least the following:

- Flow velocities;
- Soil conditions;
- Slope;
- Control and control structures;
- Water quality;
- Seepage;
- Operation and maintenance; and
- Risk of failure and consequences of failure,

4.2.10 Pumps and Motors

In selecting or specifying a pump and motor for an irrigation system, the following parameters should be considered:

- The required flow rate(s);
- The total effective head (or total dynamic head) the pump has to operate against the above flow(s);
- The power required – this depends on the above two factors;
- The speed of the pump – this may govern the type of drive employed (e.g. direct coupled electric, belt drive, etc.);
- Suction capacity – pumps are normally selected according to the above parameters and then checked to see that the suction capacity is adequate;
- The possibility of pumps running off the recommended operating range curve; and
- Consideration for servicing and cleaning.

Pump flow rate(s)

In most cases, this is the easiest parameter to select, as it is equal to the design flow rate for the irrigation system, which will already have been established.

In those cases where there is more than one design flow rate, consider whether this can best be handled by using a single or multiple pumps, or whether a variable speed drive unit or other control methods will be the appropriate choice. Alternative designs should be prepared and total annual costs (taking into account both capital and running costs) compared to arrive at an economic solution.

Total effective pump head

This is the total head the pump must impart to the water while pumping at the design flow rate. The accurate assessment of total effective head that a particular system will impose on a pump must be carried out for appropriate pump selection.

Electric motor efficiency

Electric motors vary in their ability to convert electrical energy to the mechanical energy necessary to drive pumps. Differences in efficiencies between standard motors are generally small (1-5%), but as the motor is at the start of the drive train, the savings achieved by selecting an efficient motor and ensuring that the motor operates at its best efficiency point can be substantial. Lack of control or inappropriate application can waste more energy than any motor efficiency consideration.

High efficiency electric motors are increasing in availability, mainly driven by government regulation targeted at motor manufacturers and distributors to improve energy efficiency in the US and Australia, and should be selected in preference to lower efficiency motors. Minimum Energy Performance Standards (MEPS) have been introduced in Australian Standard AS/NZS 1359:2000, which sets out minimum energy performance and labelling of motors in Australia and New Zealand. .

Motors must be properly sized and controlled, regardless of the standard of motor efficiency. Once the load aspects of the design are verified, an analysis of the financial benefits of high efficiency motors should be carried out.

4.2.11 Electrics

All electrical systems must be designed to meet local and national electrical standards and requirements.

Electrical systems for pumps should include:

- A starter type that meets local lines company and energy supplier requirements;
- Overload protection;
- High and low pressure protection;
- Running timer;
- Ammeter;
- Total hour meter;
- Power factor correction (where appropriate);
- Running light; and
- Low water level probe.

4.2.12 Control

A wide range of control methods are available for irrigation systems. They include:

- Manual systems;
- Electromagnetic control;
- Solid state control;
- Combined central/satellite control;
- Remote control; and
- Computer-based systems.

Regardless of the method of control, the designer should ensure that the irrigation system can always be operated while maintaining a safe running condition.

If automatic control is being contemplated, the following should be considered:

- The cost-benefit of various options;
- The difficulty of using the system and the level of training required;
- Reliability, repairs and maintenance;
- Availability of power supply;
- Maximising pumping time by keeping the system operating whenever required;
- Considering automatic starting or stopping from remote locations;
- Providing automatic restarting after loss of power;
- Allowing the convenience of short-term or long-term changes in duty to be accommodated without manual intervention (e.g. when shifting irrigators);
- Protecting the system from unwanted operating conditions – high pressures, water hammer, etc.;
- Improved management of irrigation system schedules allowing water savings, optimum crop quantity and crop quality;
- The ability to take advantage of time-of-use energy programmes to reduce electricity costs;
- Incorporating fertiliser injection into the irrigation system;
- Controlling filter backflushing;
- Working within available watering times for mowing, spraying, picking crops;
- Labour savings (no need to go into the field to turn valves on and off); and
- Providing information feedback, what has happened in field, and record keeping.

Precautions that should be taken into account are:

- Where an irrigation system has problems with unwanted shutdowns, the problems with the irrigation system must be sorted out first - before adding more components.
- Ensuring that safety shutdown controls always override restart controls, so that full protection is maintained;
- Setting the system up so restart attempts are minimised if other problems are likely;
- Taking account of elevation differences between pumps and irrigators;
- Ensuring that systems pumping uphill remain full;
- Ensuring pipelines running downhill have appropriate measures to control emptying of pipelines (e.g. vacuum breakers);
- Carrying out detailed analysis on systems with very high pressures, complex combinations of pumps, and very long pipelines;
- Allowing for expansion or to accommodate a change in design – many of the new systems are modular, which means that as many modules as required can be added to cover expansion;
- If the central controller is installed outdoors, housing it in a good waterproof cabinet (new stainless steel cabinets are probably best) – be aware that getting 240V power supply to an outdoor installation may add significant additional expense;
- If a system malfunctions, know what to do to fix it, or have quick access to someone who can.

4.2.13 Filtration

General

Filtration is an integral part of an irrigation system where physical or chemical impurities in the water occur and where those chemical or physical impurities can have an adverse effect on the operation and performance of the irrigation system.

For the security of long-term system performance, the selection of filtration should be matched to the source water quality and system type, i.e. to the anticipated solids load(s) and system water quality requirements. Filtration is intended to remove contaminants from source water (both organic and inorganic).

The following should be taken into account:

- The method and sizing of filters, which depends on the flow rate, type of debris, debris loading and the outlet orifice size (pore opening) of the emitting device – each situation must be considered in its own context.
- Complete removal of material from irrigation water is impractical and expensive – the level of filtration must be tailored to the required system performance.
- A good general rule concerning filtration is to be conservative, keeping below manufacturer's guidelines for pressure loss and using 80% of manufacturer's maximum flow rates through filters; and
- Other than pump intake screens, filters should never be installed on the suction side of a pump.

The recommended standards of filtration for sprinkler irrigation, micro irrigation and drip irrigation are given in Section 5.2.11.

4.2.14 Back Flow Prevention

Backflow prevention appropriate to the level of risk must be installed on all systems where contamination of water supplies is possible. This means that some form of backflow prevention should be fitted to most irrigation systems. Backflow prevention systems are always required when:

- Chemicals or contaminants are injected or could enter into an irrigation system; or
- A public (municipal) water supply is used, whether or not chemicals are injected.

Check all applicable national, regional or local municipal codes and standards to determine the type of backflow prevention device required. Choose a level of protection appropriate to the potential hazard and level of contamination risk.

The following are general guidelines to be followed when considering the need for and the type of backflow prevention on irrigation systems:

- **Public water supplies (mains supply)**
 - a) Use a reduced-pressure zone (RPZ) backflow prevention device or an air-gap separation of the irrigation system from the water supply when chemicals are

injected into irrigation systems that are connected to municipal water supplies.

- b) Use a RPZ backflow prevention device or an air-gap separation of the irrigation system from the water supply where there is any risk of contaminants entering the system.
 - c) If chemicals are not being injected into a public water-supplied system and there is no risk of contaminants entering the system, install a double check valve assembly as a safety measure.
- **Non-public water supply (e.g. irrigation well, lake or canal)**
 - a) If no chemicals are injected into the irrigation system or contaminants cannot enter the irrigation system, a standard check valve is recommended for all systems where backflow is possible.
 - b) If low hazard chemicals such as dissolved urea (nitrogen) are injected, the backflow prevention system requires at least the following:
 - Check valve on main irrigation pipeline;
 - Low pressure drain;
 - Vacuum breaker;
 - Interlocked power supplies (unless the irrigation water is always flowing);
 - A check valve between the injection and chemical supply tank; and
 - A positive shutoff valve on the chemical tank.
 - c) If higher risk chemicals or contaminants are injected, the above protection must be modified to utilise a double check assembly rather than a single check valve on the irrigation mainline.
 - d) If effluent or very high hazard chemicals are being injected, a reduced pressure zone backflow prevention device should be installed in place of the double check assembly.

4.2.15 Measurement and Monitoring

The purpose of measurement and monitoring is to provide information to assist with system performance and management. In some cases, it also provides the basis for reporting for compliance with resource consent conditions.

The incorporation of both water use measurement and soil moisture measurement should be planned for and included at the design stage of the process. Measuring water use and soil moisture can make significant savings in both water use and energy use, particularly on systems with more than adequate capacity, as it is very easy to overwater under most conditions.

Water supply

Water supply monitoring is recommended to ensure safety and reliability of system operation. The following should be included:

- Water level – For groundwater sources both in the production and associated monitoring wells, if any. This may be achieved with periodic manual methods (dip probe or suction gauge) or automatically (pressure transducer and datalogger).

- Water flow – For some surface water supplies it may be necessary to monitor flow rates as a condition of take. This may be achieved by a variety of methods using one or a combination of flow meters, gauging stations or weirs (with manual or automatic recording). The type and frequency of records is dependent on the water source and monitoring requirements.
- Water quality – The main requirement for water quality monitoring is to provide an access point for water samples to be taken. A sampling tap at the headworks of the system is recommended for all systems.

Water take

The measurement and recording of water taken provides the basis for determining overall system performance. For a number of regional councils, it is also often a required condition of the water take (resource) consent. From the clients' perspective, water take records provide the opportunity to verify system performance (i.e. actual volume of water applied versus design values). Water take records can be readily used to determine average application depth, on a single event or longer-term basis (weekly, monthly or seasonal). For more detailed evaluation of performance, it can be used to verify individual block or zone application depths.

For the purposes of routine system management, daily water use records provide the foundation for assessing application depths per cycle. Water use is generally measured with some form of flow measurement – for pressure irrigation systems, usually with a water meter, and for open channel system, with weir or gauging station. While measurements are generally made by manual recording, this is time consuming on a regular basis and, as a consequence, often unsustainable over the entire season.

Automatic logging of measurements reduces labour requirements (in terms of reading and using information), and generally provides more accurate and complete information. The meter or gauge records can be readily transferred to standard spreadsheet format for reporting or further analysis of application depths, application efficiencies, etc. Water use records (along with soil moisture measurements and, in some cases, climate data [PET]) provide the basis for the assessment of water demand and balances.

The frequency of recording is dependent on the measurement method and end application. Surface water takes are generally required to report daily water use for consent purposes to verify compliance with daily take rates, while groundwater takes are often reported on a monthly or seasonal basis to verify compliance with maximum seasonal take volumes.

The specific requirement for flow measuring devices is related to the water source, distribution system and irrigation method. Piped water supplies generally use some form of flow measurement at the source or pump.

Water meter selection criteria for meter type should be based on:

- Accuracy of reading – as specified in Section 5.2.12.
- Diameter – For in-line meters, the nominal diameter of the meter should not be less than the pipe diameter upstream and downstream of the meter.

- Installation position – Designers should allow for straight sections of pipe upstream (ten times nominal diameter) and downstream (five times nominal diameter), unless otherwise specified by meter manufacturers.
- Allowance in headworks – Designers should make allowance for and preferably include straight pipe for water meter installation in the headworks of an irrigation system at the design stage, even if meters are not initially installed.

Soil moisture

The measurement of soil moisture provides a method of directly monitoring soil water depletion and, therefore, the basis for scheduling irrigation events. The range of technology available today is rapidly expanding, increasing both the reliability of measurements and access to the data. A variety of measurement methods are available. Methods range from direct sampling, such as dig and feel, to neutron probes or weather stations. The selection of a method is dependent on factors such as irrigated area, irrigation method, soil type, crop type and climate. Table 19 (page 54) lists an overview of methods and potential applications.

4.3 Quoting and Supply

A properly prepared design report and plan must be provided to the client. For convenience, a design report template will be made available for downloading from the INZ website. There is no requirement to use the template, and it can be modified to suit an individual firm's requirements. The following information, if applicable, must be clearly visible within the report so that key performance indicators can be calculated.

4.3.1 Supplier Information

- Name of supplier
- Contact details of supplier (e.g. address, phone, fax, email, etc.)
- Name of designer

4.3.2 Client Information

- Name of client
- Contact details of client (e.g. address, phone, fax, email, etc.)
- Name of property
- Location of property
- Property area

4.3.3 Design Specification

- Effective irrigated area
- Crops grown under irrigation
- Crop irrigation rate
- Irrigation system capacity
- Soil types
- Soil water holding capacities and allowable deficits
- Soil infiltration rates

- Depths of application
- Maximum return intervals
- Application rates
- Design application uniformity or appropriate measure of uniformity
- Application efficiency expected

4.3.4 Technical Analysis

The designer should provide sufficient information to the client to show that the analysis required to arrive at the chosen design has been carried out. For example, this information should include a summary of pressure calculations, in particular, pressures at key system points, and cost-benefit analysis where alternatives have been considered.

4.3.5 Technical Supporting Information

This is information to support the design and analysis. It may be required if a client is going to obtain an independent evaluation of the design. It will almost certainly be required at some time in the future for maintenance or if changes to the design are contemplated, to compare new performance with performance changes over time, and to assess the design if something goes wrong. It should include:

- Pump characteristic curves showing duty points;
- Sprinkler/dripper performance curves;
- Specifications of irrigators;
- Specifications of pipelines; and
- Specifications of electrical equipment.

4.3.6 Bill of Materials

The bill of materials and associated rate and cost should provide a clear description of items and services to be provided under the contract so that it is very clear about what is and is not being supplied.

Materials list

This should explicitly list the following:

- Description of materials with rating or classification;
- Supplied quantity;
- Cost;
- Any contingencies included in the costing; and
- GST.

Financial information

This should include:

- Total cost;
- Exchange rate assumptions and variations to costs if they change (as far as possible, quotes should be based on a fixed price);
- Equipment costs:
 - Irrigation system components;

- Mainline and fittings;
- Pumping and related equipment;
- Electrical equipment;
- Water supply components;
- Installation costs:
 - Irrigation system components;
 - Mainline and fittings;
 - Pumping and related equipment;
 - Electrical supply and equipment;
 - Water supply components.

Any potential variations to the list and how subsequent costs will be justified and allocated must be stated. If extras due to events that result in changes to price are likely, commonplace or can be foreseen, these changes and the effect on price must be documented.

Expected operating costs

Operating costs are often an overlooked component of irrigation system design and quoting. Designers must quantify or estimate the expected operating costs in terms of the following:

- Labour to operate irrigation system (ha/hr);
- Energy costs of running the system (based on metered power or fuel equivalents); and
- Maintenance costs (time and materials).

Operating cost should also be expressed as cost per unit area (\$/ha) and cost per unit volume of water (\$/m³).

Warrantees

A written minimum 12-month warranty should be offered, with items covered and how the warranty is going to be serviced. The warranty must include:

- Period of cover;
- Retentions; and
- Who is responsible for what.

Delivery

Delivery times for all items should be listed. If any variations to delivery times occur, this should be explained to the purchaser.

4.4 Installation

Recognised industry good practice is to be used for installation of all irrigation systems. This means complying with all regulations, engineering standards, environmental requirements, and health and safety requirements. In particular, reference should be made to any relevant standards for the various parts of the system and compliance certificates issued where appropriate, for example:

- Well drilling – refer to drilling standards number

- Pipeline installations – for example, Humes pipeline manual
- Pump installation – standards from the manufacturers
- Electrical loads and works – to comply with local and national regulations
- Irrigation equipment – as per relevant manufacturer’s standards

If deviating from any of the recognised standards or good practice, the client must be notified, and the decision to accept a different standard made by the client.

4.5 Commissioning

4.5.1 Commissioning Process

The commissioning process must illustrate that all components of the system are operating properly and to design specification over the range of on-site conditions expected.

In terms of irrigation performance, the evaluation process should broadly follow the irrigation evaluation guidelines (Bloomer *et al.* 2006).

Acceptable deviation from design specification is given in Section 5.9.

If the contract includes application uniformity checks, the conditions applying at the time the checks are made must be specified in the contract.

Any variations from the original design must be documented on the as-built plan or in the commissioning report and supplied to the purchaser.

4.5.2 As-built Plan

A final clear and concise readable plan, drawn to scale, with all key items located on the plan must be provided within one month of commissioning or within one month of making changes to the system.

The plan must provide accurate locations, dimensions and sizes of all key components in the system. This is particularly important for items buried underground.

4.5.3 Report

In addition to an as-built plan, a commissioning report should be provided to the client within one month of carrying out the testing and commissioning of the irrigation system.

The report should include:

- Date of commissioning;
- Procedures followed during commissioning;
- Pressures at critical design points;
- Pump pressures and flows; and
- Electrical readings (voltage, amps, etc.) under load.

4.6 Operation and Maintenance

Health and safety issues and a description of labour skills needed to operate and maintain the system must be provided. If appropriate, training must be provided.

4.6.1 Operation and Maintenance Instructions

Operation manual

The system operation manual should specify:

- The correct way to operate all equipment and installations;
- Scheduling methods and crop water requirements;
- How the system should work and its optimal operating range;
- Protocols for operating the system safely;
- How the system handles natural extreme events such as floods and storms;
- How the system's operation will be monitored;
- How environmental impacts, such as drainage, will be monitored; and
- Emergency procedures.

Maintenance manual

A system maintenance manual should include:

- A service manual and parts book;
- A schedule of maintenance and replacement that specifies the frequency of inspection and service for all elements of the system;
- A list of monitoring points and methods and KPI values to be achieved;
- Maintenance records, as well as financial records of costs, to operate and maintain the system should be kept; and
- KPI monitoring recording sheets.

4.6.2 Servicing

How the system is going to be serviced should be made known to the purchaser. This should include charge out rates and expected response times.

Expected reliability and life of the system must also be made known to the purchaser.

4.6.3 Responsibilities of Dealer

Designer's skills

Designing an irrigation system requires a high level of skill and a professional approach. Working from the information gathered during the planning phase, the irrigation designer must be able to:

- Understand and work within the constraints of the business plan;
- Understand and use all surveys, including soil, hydrogeology and topographic surveys;
- Understand a range of technical issues, including hydraulics, soils, agronomy, hydrology, hydrogeology and engineering;
- Design the irrigation system so that it delivers the correct amount of water to the plants at the required times;
- Communicate and work closely with the client; and

- Demonstrate their competence through successful practical experience, formal qualifications and/or industry certification.

4.6.4 Responsibilities of Purchaser

A range of skills is required for the successful development and commissioning of an irrigation system. It is the responsibility of the purchaser to check that the people they contract actually have the required skills.

The skills could be held by a number of different professionals, and the particular profession that has these skills may vary from place to place. For example, in one area, an engineering practice that specialises in irrigation development may have within the practice many of the skills required. This does not mean that all engineering practices will retain the appropriate skills. Irrigators who are planning and supervising development work need to know each of the skills required so that they can find a suitably qualified person. People working on an irrigation development should be able to demonstrate their competence to undertake the tasks in several ways, including formal qualifications, previous track record, and industry certification.

Once the system has been commissioned and handed over by the installer, the responsibility for ongoing operation and maintenance lies with the manager of the system. Staff should be able to demonstrate the following skills:

- Knowledge of basic soil plant water relationships;
- Basic knowledge of hydraulics and system components;
- Ability to read plans, manuals and technical specifications;
- Ability to apply objective scheduling methods;
- Ability to plan irrigation, schedule and order water (peak and off-peak);
- Understand application rates and how many hours to water;
- Ability to monitor and understand water quality and impurities;
- Ability to test pressure/flow rates in system (valves/emitters);
- Ability to monitor pump performance, including alignment and efficiency;
- Ability to monitor and maintain surface and subsurface drainage;
- Basic knowledge of pipe repairs;
- Understand how to operate the system safely within OSH regulations;
- Ability to read water meter, rain gauge, tensiometers, and compare to benchmarks;
- Keep records/monitor/check list;
- Calibrate fertigation equipment;
- Determine the potential for off-site and groundwater impacts from operation and drainage; and
- Understand operational risks.

5 DESIGN STANDARDS

5.1 Planning

All requirements detailed in Section 4.1 should be followed to meet good industry practice.

5.2 Design

5.2.1 Water Source

All requirements detailed in Section 4.2.1 should be followed to meet good industry practice.

5.2.2 Soil-Crop-Water Relationships

The designer shall consider all of the relevant factors that determine how much water the irrigation system should be designed to apply and how often, and then design a system that meets those requirements in an efficient manner.

Total available water holding capacity (TAW)

In the absence of specific information, derive TAW from the effective root depth and the values in the following table:

Table 3: Estimated soil water holding capacity

Soil class	WHC (mm/m)
Clay loam	175-190
Silt loam, no stones or gravel	155-165
Silt loams, approx 30% gravel by volume	110-120
Sandy loam	65-110
Sand	45-55

Determine the root depth for the crop and adjust the above values accordingly. For soils with distinct layers (e.g. silt loam over stones), sum the water holding capacities according to the effective root depth.

For stones other than 30%, adjust the values according to the approximate volume of stones in the profile.

Effective crop root depths (D_r)

Average effective root depths for mature crops shall be used to determine total available water holding capacity. Where possible, localised known values for the relevant crops should be used. If local values are not available, use the values in Table 4.

Table 4: Approximate crop root depths for mature crops

Crop	Maximum effective root depth (m)
Pasture	0.3-0.8
Clover	0.3-0.6
Lucerne	1.0-2.0
Barley	0.5-1.0
Wheat	0.7-1.1
Maize	0.6-0.9
Beans	0.5-0.6
Onions	0.3-0.5
Beet	0.4-0.6
Apples	0.8-1.2
Grapes	0.5-1.0
Kiwifruit	1.0 – 1.5
Peas	0.4-0.6
Potatoes	0.6-0.9

Allowable depletion of available soil moisture (MAD)

The following is recommended to prevent plant stress and loss of production. Values depend on crop stress sensitivity and expected ET rate.

Table 5: Allowable percentage soil moisture depletion

Crops	Average weekly ET (mm/d)						
	2	3	4	5	6	7	8
Onions, potatoes, pasture (%)	50	43	35	30	25	23	20
Cabbages, peas, tomatoes (%)	68	58	48	40	35	33	28
Beans, citrus, lucerne, cereals, pipfruit (%)	80	70	60	50	45	43	38
Grapes, olives, maize, beet (%)	88	80	70	60	55	50	45

For situations where plant stress is allowed or desired, such as in regulated deficit irrigation or maintaining turf but not maximising growth, the deficits given in Table 5 may be exceeded.

Net depth of application (D_n)

This should not be greater than the allowable moisture depletion, as determined by the following formula:

$$D_n = \frac{TAW \times D_r \times MAD}{100}$$

5.2.3 Irrigation Application Rates

A spray irrigation system should apply water at a rate that does not cause surface runoff or excessive ponding on the soil surface during irrigation or after irrigation has ceased.

NZ Standards NZS 5103:1973 offers some guidance on estimated maximum water application rates for design of spray irrigation systems. These have been summarised in Table 6.

Table 6: Estimated maximum allowable water application rates

Soil group	Slope (mm/h)		
	0-8 deg	9-12.5 deg	Over 12.5 deg
Sands and shallow sandy loams	32	25	20
Sandy loams over heavy subsoil	20	17	13
Medium loams over heavier subsoil	17	13	10
Clay loams over clay subsoil	13	10	8
Silt loams and silt clays	10	8	5
Clays	6	5	4
Peat	17	-	-

Note that these rates should be used for systems typically applying more than 50 mm of water over long-time intervals – typically anything more than 1.5-2 hours.

Where small depths of water are being applied in short-time intervals, as with centre-pivots on three or four-day rotations for example, application rates can be increased according to the infiltration rates given in Figure 1. These curves are not actual soil infiltration rate curves, as they have been modified to take into account the application rate of applied water.

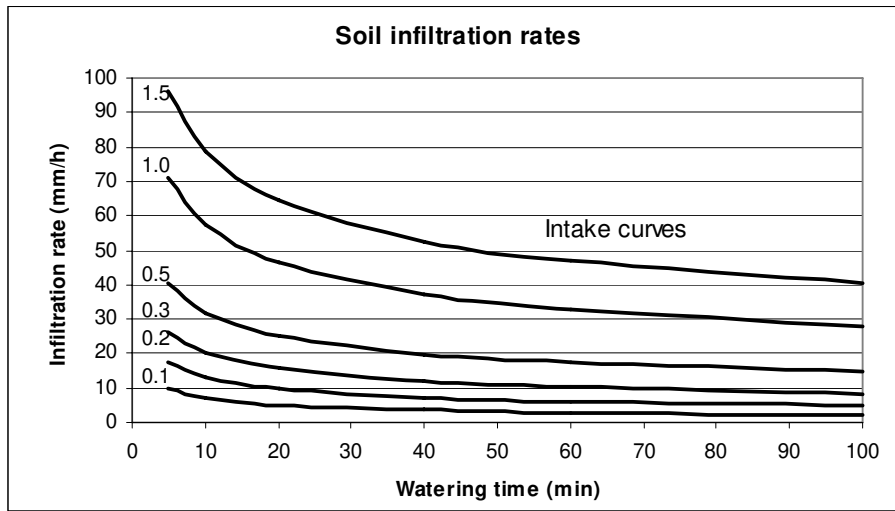


Figure 1: Soil infiltration rates according to watering time

Where specific soil information is not available on intake curve numbers, the approximate values given in Table 7 can be used with care.

Table 7: Approximate soil intake curves

Soil class	Approximate intake curve number
Tight clay	0.1
Clay/clay loam	0.1-0.2
Silt loam	0.2-0.3
Sandy, stony silt loam	0.3-0.5
Sandy loam and fine sand	0.5-1.0
Sand	1.0-1.5
Coarse sand	1.5

5.2.4 Application Uniformity

Microsprinkler and drip irrigation

Table 8 shows the recommended percentage of emission uniformity (EU_{des}) used for microsprinkler and drip irrigation.

Table 8: Recommended EU_{des} for microsprinkler and drip irrigation

Crop type	Emission uniformity (%)
Microsprinkler	85
Drip – point source	90
Drip – inline emitters	90

The minimum EU is used to calculate the available flow variation (and from that, the allowable pressure variation) for lateral and submain diameters. EU_{des} is defined in Equation 19 in Appendix A.

Manufacturers of microsprinklers or drippers should supply manufacturer's coefficient of variation ($C_{v_{man}}$) values for their products to designers to determine the allowable design parameters.

If $C_{v_{man}}$ values are not available, systems should be designed to a flow variation of no greater than $\pm 5\%$.

Spray irrigation

Either Christiansen coefficient of uniformity (CU_c) (Christiansen, 1941) or lower quartile distribution uniformity (DU_{lq}) is typically used for spray irrigation.

The formulae for calculating CU_c (Equation 15) and DU_{lq} (Equation 16) are given in Appendix B.

Recommended CU_c 's and DU_{lq} 's for different irrigation systems are given in Table 9 below.

Table 9: Recommended CU_c 's and DU_{lq} 's for various system types

Irrigation system type	CU_c (%)	DU_{lq} (fraction)
Linear move	90-95	0.82-0.86
Centre-pivot	85-90	0.76-0.82
Side roll	80-85	0.68-0.76
Hand shift	80-85	0.68-0.76
Travelling gun	75-85	0.60-0.76
Fixed boom (low pressure)	90-95	0.82-0.86
Fixed boom (medium pressure)	80-85	0.68-0.76
Rotary boom	80-85	0.68-0.76
Solid set sprinklers	85-90	0.76-0.82
Microsprinkler	85-90	0.76-0.82
Drip (point source)	90-95	0.82-0.86
Dripline	90-95	0.82-0.86
Border-strip	70-80	0.52-0.68

The irrigation system should be designed with a uniformity that takes into account future potential system types and crop types, as well as immediate needs. When applying fertilisers or chemicals through the system, the CU_c should be at least 85%, (0.76 DU_{lq}), regardless of the method of irrigation used. When applying wastewater, CU_c should be at least 70%.

When designing a system with lower uniformities, the designer must clearly explain to the client the ongoing energy, water use, crop and cost implications.

Recommended CU_c 's for different crops are given in Table 10.

Table 10: Recommended minimum CU_c 's for various uses

Crop type	CU_c (%)	DU_{la} (fraction)
Orchard/tree crops	75	0.60
Deep rooted crops	80	0.68
Standard crops, pasture, etc.	85	0.76
Shallow rooted crops	90	0.82
Frostfighting	90	0.82

Sprinkler spacing

Where a spacing to provide a desired CU_c in still air has been determined, the following adjustments should be made for windy conditions:

- Wind speed 0-6 km/h, reduce the chosen spacing by 10%; and.
- Wind speed greater than 6 km/h, reduce the chosen spacing by an additional 5% for every additional 3 km/h wind speed.

In the absence of detailed spacing data, use the information provided in Table 11.

Table 11: Recommended sprinkler spacing as a percentage of wetted diameter

Wind conditions	Spacing (% of wetted circle)	
	Agriculture	Turf
No wind	65	55% rectangular 60% triangular
Less than 6 km/h	60	50% rectangular 55% triangular
6-12 km/h	50	45% rectangular 50% triangular
Greater than 12 km/h	No greater than 40%	For each 6 km/h, reduce by 5%

Use single jet, low angle, lower pressure sprinklers in windy conditions for better performance.

5.2.5 Application Efficiency (E_a)

This depends on the type of irrigation system and expected local climate conditions. Table 12 provides average application efficiencies and efficiency ranges for typical irrigation system types found in New Zealand.

E_a is used to convert net depth of application to gross depth of application, and incorporates all losses from the outlet to the root zone of the crop.

The target E_a should be at least 80%. If systems with lower application efficiency are selected, the value assumed should be clearly indicated to the purchaser of the irrigation system.

Table 12: Approximate E_a for various irrigation methods

System type	Average E_a (%)	Efficiency range (%)
Linear move	85	80-93
Centre-pivot	85	85-94
Side roll	80	70-85
Hand shift	80	65-85
Travelling gun	70	60-75
Fixed boom (low pressure)	75	70-80
Fixed boom (medium pressure)	80	79-88
Rotary boom	80	70-85
Solid set sprinklers	80	75-85
Microsprinkler	85	80-90
Drip (point source)	90	75-95
Dripline	90	75-95
Border-strip	60	50-80

For high temperature, low humidity and high wind areas, or on low water holding capacity soils, use the lower values. For low temperature, high humidity and low wind areas, use the higher values.

Where the depth of irrigation application is designed to equal the soil moisture deficit (i.e. to return soil moisture back to field capacity), the equation defined by Seginer (1987) can be used to calculate application efficiency from CU_c . See Equation 20 in Appendix B. Otherwise, refer to Figure 2.

5.2.6 Irrigation Adequacy

The four options in Figure 2 of 80, 85, 90, 95 are the percentage of irrigated area that is designed to be fully replenished.

For example, if the coefficient of uniformity is 80%, and 80% of the crop area is to be fully replenished, the percentage of applied water that is effectively used (E_a) is 76%.

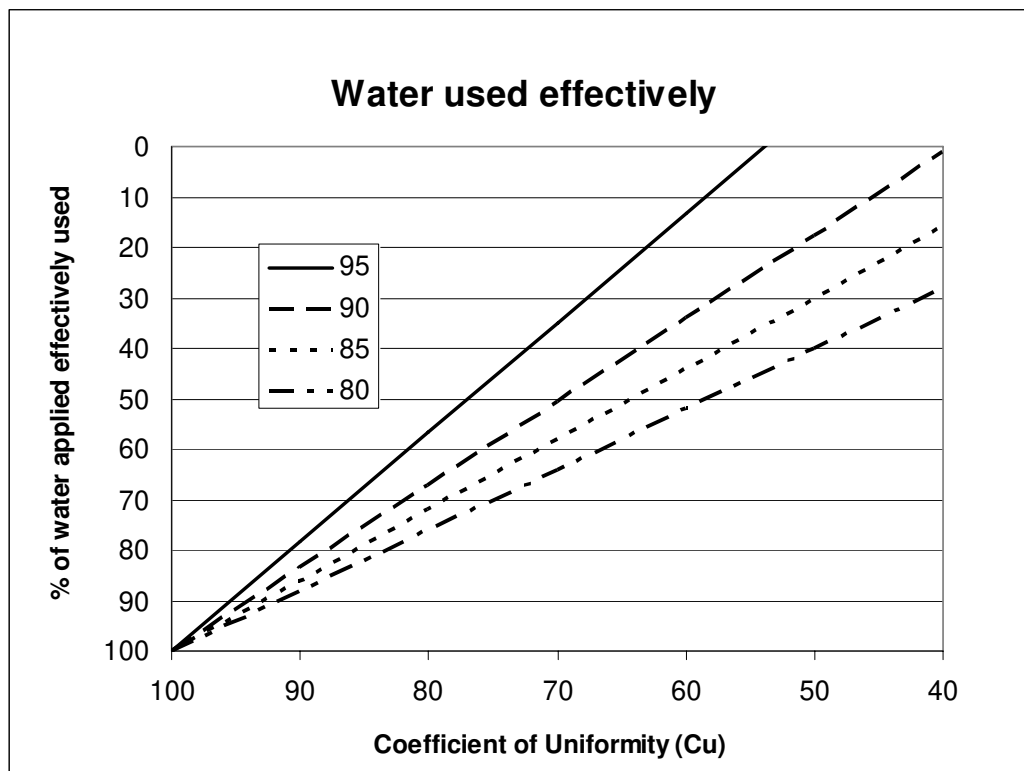


Figure 2: Effective water use for a range of Cu_c 's

5.2.7 Irrigation System Capacity (W)

The irrigation system must have the capacity to meet the reasonable needs of the crop, taking into account the following:

- Climate;
- Soil;
- Crop type;
- Irrigation method;
- Irrigation management;
- Risk of not meeting maximum demand;
- Water supply reliability; and
- Energy cost.

The appropriate design rate should be determined using locally available information and be relevant for the site. The selected value and the reasons for selection must be clearly indicated in the design proposal.

Crop coefficients (f)

The reference crop used to define crop coefficients shall be pasture, unless otherwise stated.

Table 13: Crop coefficients based on pasture

Crop	Crop factor
Pasture	1.0
Clover	1.0
Lucerne	1.2
Barley	1.0
Wheat	1.0
Maize	1.1
Beans	1.0
Onions	1.0
Beet	1.0
Potatoes	1.05
Tomatoes	1.0
Apples	0.85
Citrus	0.8
Grapes	0.8
Kiwifruit	1.0
Olives	0.7

Peak flow rates and seasonal allocations

Designers must ensure that peak flow rates of the system and seasonal crop water requirements meet irrigation scheme or regional council requirements. If resource consents are required for the taking and using of water, designers must ensure that the system meets conditions of consent.

Gross depth of application (D_g)

$$\text{Gross depth of application} = \frac{100 \times W}{E_a (\%)}$$

Return interval (I)

The interval between irrigation events should not exceed the interval determined by the following formula:

$$\text{Return interval} = \frac{D_n}{W \times f}$$

Leaching

Where saline soils are being irrigated or irrigation water contains a significant amount of salt, additional water may have to be applied to leach salts through the soil profile.

The leaching requirement should be added to the gross depth of application to determine total application depth.

5.2.8 Irrigation System Selection

Irrigation systems must be selected according to the criteria described in Section 4.2.7.

5.2.9 Hydraulic Design

Pressure loss/variation in system

Agricultural spray irrigation

Pressure variation should be measured at the outlets/sprinklers of an irrigation system. Total pressure variation at the outlets should not exceed:

- 20% of the outlet operating pressure at any point in the system; and
- 15% of the outlet operating pressure over 80% of the outlet positions on a property.

Mainline friction loss should not exceed 10 m unless there is a need to burn off pressure, such as in gravity supplied systems.

Microsprinkler or drip irrigation

- Maximum variation in flow within a block or subunit $\pm 5\%$
- Coefficient of uniformity (CU_c) 80% or higher
- Distribution uniformity (DU_{Iq}) 0.75 or higher

Turf and amenity irrigation

- Maximum variation in flow within a block or subunit $\pm 5\%$
- Coefficient of uniformity (CU_c) 80% or higher
- Distribution uniformity (DU_{Iq}) 0.75 or higher
- 10% of the outlet operating pressure at any point in the system

Maximum and minimum water velocity

In theory, there are no hard upper limits on water velocities in pipes. However, the higher the velocities, the greater the risk of damage through surges and water hammer. This particularly applies in large diameter pipes subject to uncontrolled starting and stopping. Table 14 lists recommended maximum water velocities for this situation.

Table 14: Recommended maximum water velocities

Condition/location	Velocity (m/s)
Less than 150 mm, open ended, controlled start and stop	3.0
150 mm or greater, open ended, controlled start and stop	2.0
Less than 150 mm, uncontrolled start and stop	1.5
150 mm or greater, uncontrolled start and stop	1.0

If the above figures are exceeded, then the designer must justify why the higher velocity is recommended. The designer must also advise on what measures are taken to prevent water hammer and surge damage.

For larger diameters, a full surge analysis must be undertaken to determine the risk of serious damage due to water hammer and to determine appropriate control measures.

Where velocities resulting from filling pipelines exceed the rates given in Table 14, precautions (such as controlling filling rates or using higher class pipe) must be taken.

It is possible that some pipe types, such as continuously welded polyethylene pipe, may be able to operate safely at higher velocities than those given in Table 14. Higher velocities can be used provided:

- The manufacturer of the pipe allows higher velocities to be used;
- All warranties and guarantees are not violated;
- Protection is provided to prevent damage due to surges and water hammer; and
- Pressure requirements of the system are met.

Table 15 list recommended minimum water velocities for flushing of sediment and solids from tapes and pipelines.

Table 15: Recommended minimum water velocities

Condition/location	Velocity (m/s)
Flushing fine sediment (e.g. in tapes)	0.4
Flushing coarse sediment	0.5
Flushing air, particularly in small diameter pipes	0.6
Flushing water containing solid material	1.0

Pipe friction

Where pipe sizes are not limited or controlled by pressure variation or velocity requirements, economical pipe sizes will normally have a friction loss ranging from 0.4-1.2 m per 100 m of pipe.

The most economical pipe size will depend on the current cost of pipe, the pipe life, hours of pumping, pipe friction and energy cost.

During the design process, the designer must take into account the possible effect of water quality on pipes, as well as the deterioration of pipes with age.

Designers should specify sluice valves in preference to butterfly or ball valves as isolating valves on mainlines.

Thrust block design

Thrust blocks designed according to good industry practice must be specified and installed on piped systems so that they provide the necessary support for the life of the pipeline.

Air release

Air release valves must be installed on all pipelines according to good industry practice.

5.2.10 Pumps and Motors

Many types of pumps are available, but usually only one or two will best match a design. Using an oversized pump will ultimately result in higher operating costs. It is usually more economical in the long term to select the most efficient pump, even if it requires spending a little more.

Safety factor for wear and tear

These values should be added to the calculated system capacity and used to indicate the duty point (pressure and flow) when selecting a pump.

Table 16: Recommended safety factors for pump duties

Condition	Additional capacity (%)
Discharge	5-10
Pressure	5

Where an irrigation pump is pumping water of poor quality such as that containing significant sand (more than 6 specs in a standard cup) or used for the mixing and application of abrasive fertilisers, the additional capacity rates should be doubled.

Pump efficiency

Pumps should be selected so that they operate at or near their maximum efficiency points as much as is reasonably possible. As different pumps have different levels of efficiency, pumps with the highest level of efficiency at the operating point should be selected, subject to acceptable economic capital and operating costs.

As a general rule, efficiencies for centrifugal pumps, in general, vary with flow rate, as illustrated in the following table.

Table 17: Typical efficiencies for properly chosen centrifugal pumps

Flow rate (m ³ /h)	Typical efficiency (%)
5	36
10	47
20	60
30	65
50	69
100	74
200	78
300	80
500	81

Pumps should not be selected to operate at efficiencies below these values, unless the reasons for the selection and implications of operating at low efficiencies are made known to the system purchaser.

Motor efficiency

Motors should be selected that have efficiencies close to or higher than those given in Figure 3. Note that large motors are more efficient than small motors, and that submersible motors are less efficient than standard motors. Also, 4-pole motors are less efficient than 2-pole motors (data not shown).

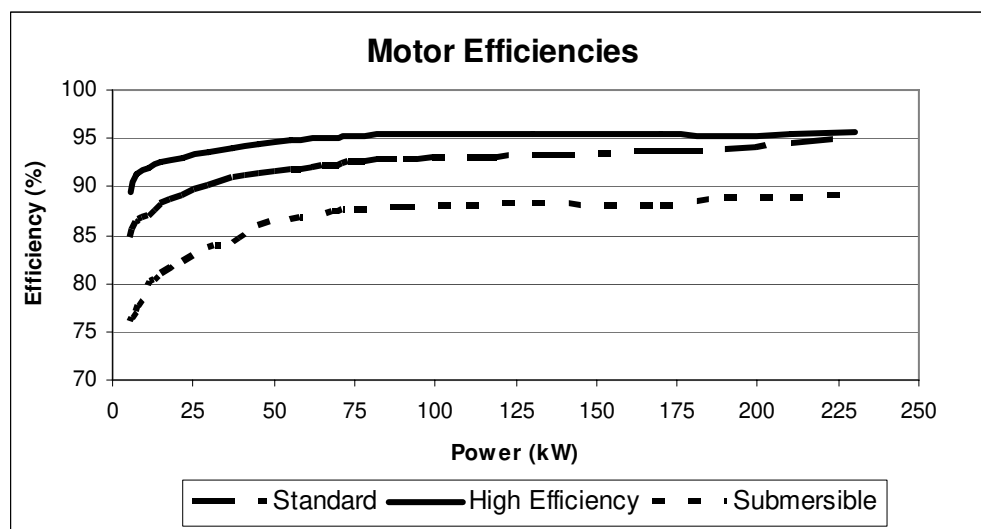


Figure 3: Motor efficiencies

The above figure shows the average efficiencies for a range of motor types taken from data supplied by motor manufacturers. Efficiency can vary by about 2.5% above and below the average for small motors through to about 0.5% above and below the average for large motors.

Figure 3 illustrates that the efficiency of surface mounted motors are 5-10% higher than the efficiency of submersible motors. This means that there may be energy

advantages in using combination of submersible and surface pumps for supplying water from deep wells.

Efficiency versus motor load

Electric motors should be matched to pumps so that they operate at greater than 95% of maximum motor efficiency under normal operating conditions. Placing large motors on small pumps should be avoided.

When calculating motor loads and energy use, manufacturer's guidelines for motor efficiencies should be used. Where manufacturer's data is not available, the values given in Figure 4 can be used.

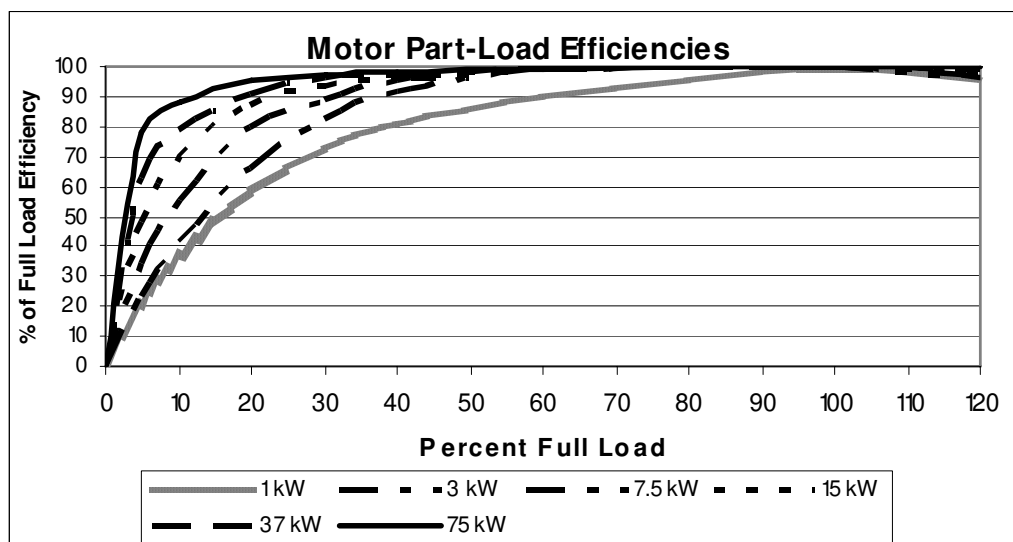


Figure 4: Part load motor efficiencies

Figure 4 demonstrates the effect that operating at loads less than 100% of the rated load has on motor efficiency. The reduction in efficiency under less than full loads is greater for small motors than for large motors.

Small motors in particular should be operated at as close to full load as possible. Larger motors (most irrigation pumps) should be sized to operate at a load of 65-100% of full load. The common practice of over-sizing motors results in less efficient motor operation. Although in some situations it is necessary to over-size motors to accommodate short-term peak loads, it is better, if possible, to design systems to avoid peak loads.

5.2.11 Filtration

Table 18 provides guidelines on screen sizes and particle sizes. Equivalent sizes are given in millimetres. Multiply by 1000 to obtain sizes in microns.

Table 18: Classification of screens and particle sizes

Screen mesh number	Mesh equivalent diameter (mm)	Particle description	Particle equivalent diameter (mm)
16	1.18	Coarse sand	>1.0
20	0.85	Medium sand	0.25-0.50
30	0.60	Very fine sand	0.05-0.50
40	0.425	Silt	0.002-0.05
80			
100	0.15	Clay	<0.002
120			
140	0.106	Bacteria	0.0004-0.02
170	0.09	Virus	<0.0004
200	0.075		
270	0.053		
400	0.038		

Sprinkler irrigation

In manually controlled systems, the size of the mesh orifices should be no more than one quarter of the sprinkler outlet diameter.

In systems with automatic valves, the manufacturer's specification should be followed, or a minimum of 80 mesh used.

The choice of filter element between molded screen and grooved disk depends on what is to be filtered. Generally, grooved disks should only be used for organic matter or algae. A fair comparison of filter types and brands can be made by looking at the effective filter area.

Maximum recommended velocity in filters is 0.5 m/s.

Micro irrigation

Ring/mesh filter openings must be no greater than one fifth that of the emitter orifice diameter. The manufacturer's recommendations for the appropriate micro emitter must be used for flow.

The recommended maximum allowable pressure drop over ring/mesh filters (in addition to normal headworks pressure losses) is as follows:

- Recommended pressure drop over a clean ring filter = 10 kPa
- Recommended pressure drop over clean filter bank = 30 kPa
- Maximum allowable pressure drop over a filter bank before backwashing = 70 kPa.

Drip irrigation

The size of the mesh or ring orifices should not be more than one seventh of the drip emitter's outlet diameter.

When using a sand filter, a secondary control mesh or ring filter must be placed on the downstream side of the sand filter to catch the impurities in case of damage to the sand filter. The drip manufacturer's recommendations must be followed when using filters. The following is suggested in the absence of manufacturer's data:

- Maximum allowable flow rate through a clean sand filter of 50 m³/h per m² with a maximum pressure drop over the sand filter of 10 kPa
- Total maximum allowable pressure drop over a clean sand filter with ring/mesh filters (including sand and ring filters) of 40 kPa
- The maximum allowable pressure difference over the filter bank before backwashing or cleaning of 60 kPa.

Other

For automatic backflushing systems, allow for potential damage due to water hammer and surge.

5.2.12 Measurement and Monitoring

Install a pressure gauge at the pump outlet to enable regular checking of pump performance. For accurate reading, the distance from a pressure gauge to a valve should be at least three to five times the diameter of the pipe.

Flow meters are often required as conditions of water takes.

An ammeter installed on the motor will also show any dramatic change in energy use, and indicate a potential problem.

5.3 Pump Suction Issues

5.3.1 Suction Lift

Allowable suction lift by a pump depends on atmospheric pressure, water vapour pressure, pressure losses, and the required inlet pressure of the particular pump. Elevation (height above sea level) and water temperature effects (fluid specific gravity and viscosity) must also be considered.

Centrifugal pumps

In general terms, the following should be followed:

- Suction lift should be kept to a realistic minimum;
- Actual net positive suction head (NPSH) should be calculated and be less than the required NPSH recommended by the pump manufacturer; and
- The system must be designed in accordance with manufacturers' performance guidelines.

5.3.2 Cavitation

The temperature at which a liquid will vaporise (boil) drops as the pressure on the liquid is reduced. As water passes through a pump it may, if the suction lift is too

great, pass through a region where the pressure is low enough for the water to vaporise locally. Bubbles of water vapour produced in this way are carried through the impeller until they reach a zone of higher pressure where they will collapse violently or implode with sufficient force to cause pitting and erosion of the impeller. The process of formation and collapse of water vapour bubbles is called cavitation. Anything that causes the pressure at the pump suction, or within the pump, to fall to below the vapour pressure of water will cause cavitation.

Cavitation in a pump is highly undesirable and, as well as causing mechanical damage, gives rise to one or more of the following:

- A metallic cracking noise from the pump inlet;
- Severe vibration;
- A fall off in performance;
- Small fragments of impellers may be found in severe cases;
- The pump may also lose its prime; and/or
- Damage to the pump bearings, which may cause catastrophic failure of the pump.

Because of the dependence of vapour pressure on temperature, this problem is accentuated when pumping liquids at elevated temperatures. However, this is seldom a consideration in irrigation design.

In new installations, failure of a pump to meet manufacturer's performance specifications, in addition to noise and vibration, may be an indication of cavitation. It is vital, therefore, to design the system to prevent cavitation from the outset.

In theory, water can be lifted from a depth of approximately 10 m. In practice, however, because of pipe friction in suction lines or pressure losses at pump entrances and because of the effect of water vapour formation, it is not possible to lift water from a depth of 10 m. Practical limits depend on water temperature, the design of the pump, and the design of the suction pipe and fittings.

Design analysis should be carried out to eliminate problems associated with cavitation by avoiding or allowing for:

- Lifting water from excessive depths;
- Using pumps not designed for high suction lifts (high NPSH requirements);
- Suction pipes too small or too long;
- Inadequate submergence over a foot valve, end of suction pipe, or above a submersible pump inlet;
- Components in the suction line with excessive pressure loss through them (e.g. poorly designed foot valves, globe valves or high-loss fittings);
- Warm water;
- Aeration due to cascading water;
- High velocities past submersible motors;
- Shrouds on submersible pumps too small or partially blocked;
- Leaks in the suction allowing air to enter; and
- Pumps running at low pressure and high flows (e.g. filling mainlines).

5.3.3 Net Positive Suction Head (NPSH)

NPSH is defined as absolute pressure (rather than gauge pressure) that is required at the pump inlet for satisfactory operation.

After the pump has been selected, a check must be made to ensure that the NPSH available (NPSHA) is greater than the NPSH required (NPSHR) for the pump.

NPSH available (NPSHA)

To calculate the absolute pressure available at the inlet, add up the available pressure and subtract any pressure used up by losses prior to water arriving at the pump inlet:

$$NPSHA = \text{Atmospheric pressure} \pm \text{any static head} - \text{friction head} \\ \text{(including minor losses)} - \text{velocity head} - \text{vapour pressure of} \\ \text{water at operating temperature}$$

Note that the vapour pressure of water at 20 degrees is about 0.25 m. Irrigation pumping plants are unlikely to be handling water at higher temperatures than this.

The NPSHA depends on the particular system involved and will be affected by conditions such as altitude (atmospheric pressure) and temperature.

NPSH required (NPSHR)

The NPSHR depends on the design of a particular pump, and is not affected by external conditions. It is specified by the pump manufacturer.

5.3.4 NPSH Margin

Under standard hydraulic definitions, the NPSHR of a pump is the NPSH that will cause the total head to be reduced by no more than 3%, as a result of flow modification caused by cavitation (vapour formation) in the pump impeller vanes (Budris, 2000).

NPSHR is ***not*** the point at which cavitation starts. The point at which cavitation starts, known as incipient cavitation, can be at a NPSHA from 2-20 times NPSHR, depending on pump design and where it is operated relative to the best efficiency point. This implies that many pumps will be operating with some cavitation. Only in severe cases associated with noise, vibration, damage and energy use will it be apparent.

The higher incipient-cavitation margins are normally associated with high suction energy, high specific speed pumps with large impeller inlet areas or reduced flow operation in the region of suction recirculation (ANSI/HI 9.6.1, 2000).

Figure 5 shows a typical relationship between NPSH margin ratio and reliability factor for centrifugal pumps.

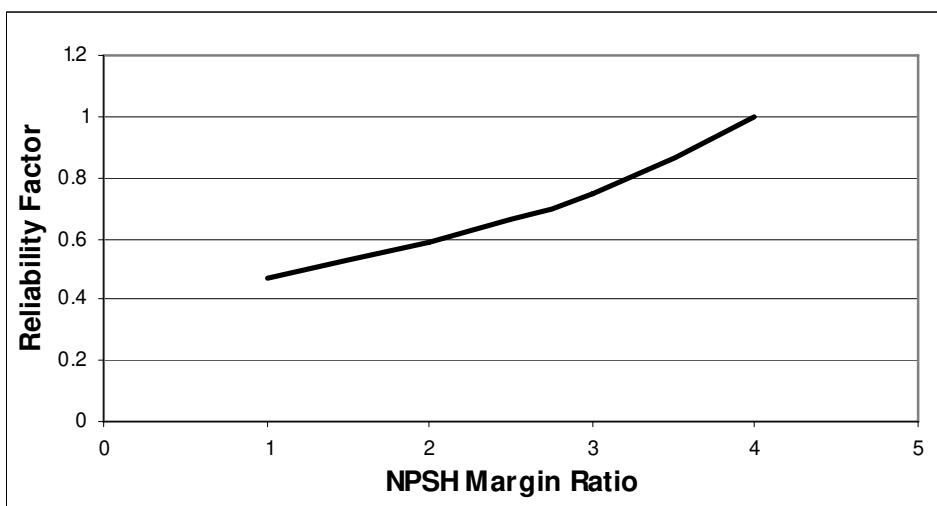


Figure 5: NPSH margin ratio

To improve pump reliability, pumps should be selected and installed so that NPSHA is not less than $NPSHR + 0.6 \text{ m}$, but as high as is practically and economically possible. If the NPSHA is less than $NPSHR + 0.6 \text{ m}$, the reasons for designing systems to a lower value and the consequences of a lower value must be explained to the purchaser.

5.3.5 Measurement and Control

Water levels

For groundwater sources in production bores and associated monitoring wells. This may be achieved with manual methods (dip meter or suction gauge) or automatically (pressure transducer and datalogger).

Water flow

For water supplies, it may be necessary to monitor flow rates as a condition of take. This may be achieved with a variety of methods using one or a combination of flow meters, gauging stations or weirs (with manual or automatic recording). The type and frequency of records is dependent on the water source and monitoring requirements.

Water quality

As this is normally associated with consent conditions, the requirements of those conditions must be followed.

Soil moisture

Table 19 lists an overview of methods and potential applications.

Table 19: Soil moisture measurement methods

Method	Description	Application
Dig & feel	Direct excavation of sites	Simple but inaccurate approach
Tensiometers	Permanent or portable measurement of soil tension (suction)	Suited to horticultural applications in-direct measurement method
Electrical conductance	Variety of devices, commonly portable	Simple to use but of limited accuracy
Neutron probe	Access tube installed at sample sites	Monitoring service with report results and recommendations
TDR (time domain reflectory)	Permanent or portable access rods directly recording water content	Suited to a range of applications
TDT (time domain transmission)	Permanent buried cables directly recording soil properties related to soil moisture	Suited to a range of permanent applications

5.4 Pump Design and Installation

5.4.1 Surface Mounted Centrifugal Pumps

A typical surface mounted centrifugal pumping plant should be designed and installed according to the following guidelines:

- As a rule-of-thumb, total suction lift for centrifugal pumps should not exceed 6.0-7.5 m, if not expressly allowed by the manufacturer. The specific conditions at a particular installation must be considered.
- Strainers should have a total open area equal to a minimum of five times the area of the suction pipe, with the upper limit dependent on water quality.
- The suction assembly should be fully air-tight.
- The foot valve should be fitted just above the strainer to prevent water draining away from the pump while it is stopped.
- Keep the submergence of the suction pipe or foot valve submerged to a depth of at least six times the diameter of the suction pipe.
- Suction pipes should be as short as possible – refer to NPSH requirements.
- The distance from an elbow to the suction valve of the pump should be at least three to five times the diameter of the pipe.
- Flexible couplings should be fitted between pumps and rigid installations (suction or discharge) to prevent failure due to vibration.
- Do not put any unnecessary valves or bends in the suction line. Keep the suction pipe as clean and straight as possible. If a valve is needed in the line, make it at least the same diameter as the suction pipe.
- The suction pipe should be at least as large as and preferably one standard pipe diameter above the size of the pump inlet.

- Use long radius bends to minimise friction loss where suction is likely to be a problem.
- The suction line should slope uphill all the way from the strainer to the pump to prevent air pockets developing.
- Eccentric, rather than concentric, reducers with the straight side fitted uppermost should be used to connect the suction line to the pump. Again, this is to prevent air pockets forming.
- If running water into a sump and pumping from a sump, ensure that the inlet pipe to the sump is below the pumping level in the sump to prevent aeration.
- Design the system so that shrouds, foot valves and filters or screens on the suction side can be kept clean.
- A valve should be fitted to the highest point on the pump casing to allow air to escape when priming the pump.
- A tee with the branch either plugged or closed off with a valve should be fitted on the discharge line for priming purposes. The top of this tee should be higher than the valve outlet to enable the casing to be completely filled. A short length of pipe may be required between the tee and the plug to ensure this.
- If a check valve is fitted, it should be placed after the pump and the gate valve. In situations where the mainline rises above the pump, it is useful to have a small diameter bypass pipe (say, 12 mm) round the check valve and controlled by a small gate valve. Water stored in the mainline can then be bled past the check valve and used to prime the pump when necessary.
- It is very useful to have two pressure gauges (or one gauge that can be connected to two points by suitable small valves) connected to either side of the gate valve. The one on the pump side then provides some indication of pump performance, while the mainline pressure is given by the other. The downstream gauge tapping should be at least 6 to 8 pipe diameters past the gate valve to avoid errors due to turbulence caused by the valve. Pressure gauges are only useful if they are in good condition and are reasonably accurate. Pressure surges and vibration are probably the main causes of pressure gauge failure. Gauges should be mounted on a firm surface (such as the wall of the pump house) and connected to the discharge line with flexible tubing. Stopcocks should be provided on the lines to the gauge to enable it to be isolated from the flow. These should only be turned on when a reading is required, and left off at all other times.
- A foot valve's "open" area must be four times that of the open area of the suction pipe, ensuring that the velocities through the foot valve do not exceed those of the suction pipe by more than 25%. The following is proposed:

Table 20: Allowable suction velocities

Suction pipe	1.5 m/s
Suction strainer	0.4 m/s

- Velocities through the suction pipe and strainer should be less than the values given in Table 20.

5.4.2 Submersible Pumps

Because of the absence of a suction line, the fittings for a submersible unit tend to be simpler than those for a surface mounted unit. The following guidelines should be used:

- Unless otherwise stated as a condition of consent, a concrete slab or wedge approximately 1.5 m square and 100 mm thick should be formed around the top of a well/bore to prevent the possibility of any contaminants seeping down the outside of the well casing into the aquifer system.
- The wellhead plate should preferably be welded to the casing if possible. Alternatively, hook bolts should be cast into the slab for bolting down the wellhead plate.
- Column material should be corrosion resistant and able to easily carry the weight of pump, cables, column and water.
- The velocity of water in columns should not exceed 2.5 m/s.
- Column guides or centralises should be attached to or welded to the column at a maximum of 12 m spacing.
- A probe tube should be installed in all wells to allow water levels to be monitored. This consists of a length of 20 mm diameter (or larger) low density polyethylene pipe (or similar) strapped to the rising column and attached to a suitable pipe fitting welded into the wellhead plate. The probe tube should extend to the top of the pump. Kinks should be avoided.
- Electric cables should be attached to the rising column at spacing not exceeding 3 m, using high quality, long-lasting tape.
- A gate valve and check valve should be fitted at the wellhead as standard practice.
- If a check valve is fitted into the column, it must be placed at a height no greater than 7 m above the lowest expected static water level.
- The same comments regarding pressure gauges that were made for surface pumps apply equally well to submersible installations.
- Make sure that rising column pipes on submersible pumps are not leaking. Leaking pipes could cause the pump to run at high flow rates and hence increase the suction requirement.

5.4.3 Friction Loss Past Submersible Motors

The passage of water through the annular space between a submersible pump motor and the well casing creates friction that results in loss of head over the pump. If velocities are high and motors are long, the loss can be substantial.

Although there are no absolute limits on maximum velocities in the annular space, velocities should not exceed 5 m/s, unless otherwise allowed by pump manufacturers.

Minimum velocities are specified by pump manufacturers to ensure sufficient motor cooling occurs. This is particularly important on pumping systems that are fitted with variable speed drives, as low velocities can arise at low flows. If a minimum velocity is not specified, a value of 0.3 m/s should be used as a guideline.

Information that enables the annular loss to be calculated should be provided by submersible pump manufacturers.

5.5 Pump Electrics

All pump starting and control systems must be:

- Installed according to manufacturer's recommendations;
- Meet required electrical regulations; and
- Have an electrical compliance certificate.

Care must be taken to minimise electrical interference and noise resulting from the use of variable speed drives.

5.5.1 Submersible Pumps

Voltage drop from power supply point to pump motor to be according to manufacturer's requirements.

If voltage drop is not specified, it must be the lesser of 5% of nominal operating voltage or 15V. This includes voltage drop in submersible pump cables.

5.6 Control

There are three main methods of controlling the operation of irrigation systems:

- Manual;
- Electric (or electronic); or
- Hydraulic.

There are a number of options designed around these main methods. Control may be computerised, radio links rather than hard wiring, or hydraulic tubes may be used. Cell phone communications technology is freely available and internet-based systems are becoming more widely used.

The design must provide the ability to allow the system to be operated in a way that:

- Meets customers needs;
- Can be easily started and stopped;
- Can be run for varying times; and
- Operates within the constraints of the system.

To meet customer needs, it may be necessary to design a control system that allows variable demand, not on fixed timers, for example.

Key aspects to consider are:

- Overall ability of the system to control irrigation;
- Flexibility of control;
- Reliability;
- Flexibility of pumping system to meet control requirements;
- Cable sizes (if using existing system);

- Quality of installation (e.g. wire joints);
- Quality of power supply and communications links;
- If computerised, speed of computer;
- Compatibility between software and hardware;
- Future expansion; and
- Addition of fertiliser injection.

Recommendations are:

- In systems with varying or multiple demand points (such as horticultural blocks), control should be able to be managed to operate pumps at maximum pump efficiency and uniform flow rates.
- Efficiency of the schedule relative to available flow must be considered.
- Included in the supply must be provision for support, manuals, backup and training. Remote access and messaging should be given serious consideration.
- In all cases, manufacturers' recommendations must be followed.
- Where possible, all stations should carry similar flows and operate against similar heads.
- Select wire sizes so that the inrush voltage at the valves is at least 20 VAC for 24 VAC systems.

5.6.1 Headworks

General construction recommendations

- Use galvanised steel to construct headworks for any pipework above ground (i.e. to the point that the pipeline goes underground and, in particular, inside pump sheds).
- Support the headworks system so components or piping does not carry heavy loads.
- Design the headworks to incorporate unions or flanges to allow system to be dismantled non-destructively.
- Minimise friction losses using low loss components such as swept bends rather than standard elbows.
- Do not use PVC or similar materials for sections of the system subject to high pressure or surges.
- If using PVC or similar materials (only recommended for small low pressure systems less than 2 kW):
 - Use heavier walled material (e.g. PN12);
 - Use increased support components to reduce load carrying requirement of PVC; and
 - Allow for malfunction (e.g. PVC getting hot and failing).

Pressure loss

- Maximum pressure loss to be 3 m on basic headworks (i.e. excluding pressure control, filtration).

Water meter

- Meters must be installed to meet manufacturer's recommendations.

- If not installed, include straight piece of pipe length at least 15 times diameter of pipeline so that a meter can be installed at a later date, or portable meters can be used.

Pressure gauges

- Fit one on high pressure side of system and one on mainline side of system.
- Pressure gauges to be fitted with isolating stopcocks or similar so they can be turned off to prevent damage.
- Fit tappings that can also be used for fitting pressure transducers or other control/monitoring devices.

Control valve

- A control valve should be fitted to all systems.
- As a minimum, use a butterfly valve, or preferably a fully retractable gate valve.
- Do not use valves that can only be fully open or fully closed in situations where the system can be started with empty mainlines.

Air release

- An air release with isolating valve should be fitted to highest point in system.
- If inside pump shed, exhaust should be routed to outside of shed.

Vacuum breaker

- In any installations where vacuum is likely to occur, a vacuum breaker should be fitted.

Fertiliser injection

- If not part of the installation, allow for possible connection of fertiliser injection into the system (e.g. by fitting bungs).
- Size of bungs to be determined according to expected injection flow rates.
- Injection points to be placed downstream of backflow prevention points.
- A backflow prevention device must be installed on bores and potable water systems if fertiliser injection is used.
- Systems must be installed to meet local regulations.

Drainage

- Facility to drain the headworks or irrigation system to ground to be included.

Frost protection

- Lagging or other protection to be provided on systems subject to freezing.

Multiple pumps

- Manifold used to link pumps together should be designed so that pumps can be independently isolated.
- In situations where maintaining supply is critical or the consequences of not maintaining a supply are severe, isolation of pumps must be allowed for.

Order of components

- For clean water installations, order should be: *control valve* → *water meter* → *check valve* (recommended).
- For dirty water installations, ensure that filters are installed upstream of any sensitive valves.
- If using effluent, fertiliser or chemical injection, injection point must be downstream of any back flow prevention devices.

5.7 Measurement and Monitoring

Unless otherwise specified or agreed, the following is to be applied:

Bore water level

Accuracy of measurement to be 0.1 m unless otherwise specified.

Flow rate

Accuracy for piped water systems (pipes flowing full) ±5%

Accuracy for surface water flows ±10%.

5.8 Installation

Reference should be made to any relevant standards for the various parts of the system and compliance certificates issued where appropriate, as described in Section 4.4 :

5.9 Testing and Commissioning

The acceptable deviation from design specification will be:

- Flows = ±5%
- Pressures = ±10%
- Current (amps) = ±5%
- Uniformity = not more than 5% (or 0.05) under that specified

If values other than those above are adopted, they must be agreed with the client during the design process and included in writing in the quote/contract.

The filling up of pipelines and examples of mainline design must be according to industry standards, which must be covered in manuals specific for designers. This may include reference to specific standards or approaches for testing of pipelines (i.e. pressure testing).

If no specific standards are available, pipes should be pressurised to 1.5 times the maximum design working pressure of the pipe for a period of one hour.

Pressure testing must not occur within 24 hours of installation of pipes with solvent welds.

The commissioning procedure should be outlined so that it is formally completed and reported on, with a list of specific measurements (i.e. operating pressures, flow rates, etc.).

6 DESIGN PERFORMANCE TABLE

Table 21 is provided as an example of how key performance indicators can be included in a design report. Appropriate values for each design should be included.

Table 21: Design summary

Design outputs	Unit(s)	Value
<i>Background Information</i>		
Effective irrigated area	ha	
<i>Crop and Soils</i>		
Crop irrigation rate	mm/d, m ³ /ha/wk	
System capacity (based on 24 hours)	ℓ/s/ha, mm/d	
Management allowable deficit	mm	
Application depth range	mm	
Return interval	days	
Soil infiltration rates	mm/h	
<i>Hydraulics</i>		
Irrigation application rates	mm/h	
Application uniformity	CU%	
Adequacy of irrigation	%	
Application efficiency	%	
Distribution efficiency	%	
Headworks losses	m	
<i>Energy Use Efficiency</i>		
Pump sizes	kW	
Energy per unit volume	kW/m ³ /h	
Energy per unit area	kW/ha	kWh/ha
<i>Labour Efficiency</i>		
Hours per hectare per year	hr/ha	
Hours per millimetre applied	hr/mm	
<i>Capital Efficiency</i>		
Capital cost per hectare	\$/ha	
Annual operating cost per hectare	\$/ha	
Total annual cost per hectare	\$/ha	
<i>Environmental Performance</i>		
Average system efficiency	%	
Drainage	%	
Runoff	%	

7 REFERENCES

Christiansen JE, (1942): Irrigation by sprinkling. *California Agric Expt Station Bulletin* No 570.

Seginer, I (1987): Spatial water distribution in sprinkle irrigation. *Adv in Irrigation* 4.

Appendix A: Abbreviations and symbols

A	Area of the irrigated strip (m ²)
AE	Application efficiency
CU_c	Christiansen coefficient of uniformity
C_v	Coefficient of variation
Cv_{man}	Coefficient of variation due to manufacturing
D_{app}	Applied depth
D_c	Critical deficit
DU	Distribution uniformity
DU_{lq}	Low quarter distribution uniformity
$E_{hydraulic}$	Hydraulic efficiency
E_{pump}	Pump efficiency
ET_{crop}	Crop water use by evapotranspiration
EU	Statistical emission uniformity
EU_{man}	Manufacturer's emission uniformity
I_i	Reference application rate
IA_{lq}	Low quarter irrigation adequacy
IR	Irrigation requirement
K_d	Emitter discharge coefficient
L_e	Effective length
L_t	Travel path length
MAD	Management allowable deficit
N_e	Number of emitters per plant
p	Operating pressure
P_s	Sprinkler pressure

PET	Potential evapo-transpiration
q	Emitter flow rate
Q_m	System flow rate (m ³ /h)
r_e	Effective radius
r_w	Wetted radius
RAW	Readily available water
s	Standard deviation in the sample
SMD	Soil moisture deficit
TAW	Total available water
T_{irrig}	Duration of an irrigation event
WHC	Soil water holding capacity
WR _b	Beneficial water requirement applied by irrigation system
x	Emitter discharge exponent

Appendix B: Standard formulae

EFFICIENCY CALCULATIONS

Equation 1: Potential soil moisture deficit (PSMD)

A measure of moisture stress experienced by a crop, calculated using:

$$PSMD = SMD - D_c : SMD > D_c$$

Where: $PSMD$ = Potential soil moisture deficit in any period where $SMD > D_c$

SMD = Soil moisture deficit

D_c = Critical deficit

Equation 2: Seasonal potential soil moisture deficit ($PSMD_{season}$)

Seasonal PSMD is calculated from soil moisture budgets by summing all deficits below the critical deficit (or MAD):

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

Where: $PSMD_{season}$ = Seasonal potential soil moisture deficit

$PSMD_1$ = Potential soil moisture deficit in the first period

$PSMD_n$ = Potential soil moisture deficit in the n^{th} period

Equation 3: 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.

$$SDP = \sum (DP_1 : DP_n)$$

Where: SDP = Seasonal deep percolation

DP = Deep percolation in periods 1 to n

Equation 4: 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 = Seasonal deep percolation from irrigation

SAE = Seasonal application efficiency

Equation 5: Drought induced yield loss (YL_{dt})

Calculated from potential (client expected) yield, PSMD and the drought response factor:

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

Where: YL_{di} = Drought induced yield loss
 Y_{pot} = Potential yield (t/ha)
 $PSMD$ = Potential soil moisture deficit (mm)
 F_{dr} = Drought response factor (%yield / mm PSMD)

Equation 6: 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 = The value of lost yield (\$/ha)
 YL_{di} = Drought-induced yield loss
 $Price$ = Price paid per unit yield

Equation 7: Irrigation requirement (IR)

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

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

Where: IR = Irrigation requirement
 ET_{crop} = Crop water use by evapotranspiration
 WR_b = Beneficial water requirement applied by irrigation system
 P = Precipitation
 ASM = Available soil moisture
 DU_{lq} = Low quarter distribution uniformity

BASE CALCULATIONS

Equation 8: 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 = Coefficient of variation
 s = Standard deviation in the sample
 \bar{x} = Mean value from the sample

Equation 9: Standard deviation from the mean (s)

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

Where: x_i = Performance of an individual within the sample
 i = Number assigned to identify a particular individual
 n = Number of individuals in the sample

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

Equation 10: 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 = Emitter flow rate
 K_d = Emitter discharge coefficient
 p = Operating pressure
 x = Emitter discharge exponent

Equation 11: 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 = Emitter discharge exponent
 p_1 and p_2 = Pressures
 q_1 and q_2 = Flows at p_1 and p_2 respectively

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

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.

Equation 12: 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.

Equation 13: Manufacturer's emission uniformity (EU_{man})

Manufacturer's emission uniformity is determined from physical laboratory measurements at a standard temperature.

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} = Manufacturer's emission uniformity
 Cv_{man} = Coefficient of variation in manufacturing

UNIFORMITY CALCULATIONS

Equation 14: 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} = Lowest quarter distribution uniformity coefficient
 \overline{V}_{lq} = Average volume (or alternatively the mass or depth) of water collected in the lowest quarter of the field
 \overline{V} = Average volume (or alternatively mass or depth) of water collected by all collectors used in the data analysis

Equation 15: Christiansen coefficient (CU_c)

The Christiansen formula is:

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

Where: CU_c = Christiansen coefficient of uniformity
 n = Number of collectors used in the data analysis
 i = Number assigned to identify a particular collector
 V_i = Volume (or alternatively the mass or depth) of water collected in the i th container

\bar{V} = Arithmetic average volume (or alternatively mass or depth) of water collected by all collectors used in the data analysis, calculated as:

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

Equation 16: Emission uniformity (EU)

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

$$EU = (1 - Cv)$$

Where: EU = Statistical emission uniformity
 Cv = Coefficient of variation

Equation 17: Emission vs Distribution uniformity

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

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

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

Equation 18: Emitter emission uniformity (EEU_{lq})

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

Where: EEU_{lq} = Emitter emission uniformity
 Cv_{man} = Coefficient of emitter manufacturing variation
 Cv_{defect} = Mean coefficient of variation due to blockages, wear and tear determined from emitter tests 1, 3 and 4.
 n = 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.

Equation 19: Design uniformity (EU_{des})

(Keller & Karmeli, 1974: ASAE 405.1)

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

Where: EU_{des} = Design emission uniformity
 Cv_{man} = Manufacturer's coefficient of variation of emitters
 n = Number of emitters per plant

- q_m = Mean low quarter emitter discharge due to the mean low quarter pressure
- q_a = Overall mean emitter discharge

Equation 20: Application Efficiency

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

APPLICATION CALCULATIONS

Equation 21: Total system application depth (D_{mf})

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

- Where: D_{mf} = Mean application depth based on system flow rate (mm)
- Q_m = System flow rate (m³/h)
- T_{irrig} = Duration of an irrigation event
- A = Area of the irrigated strip (m²)

Equation 22: Infiltration depth (drip-micro and long-lateral)

$$D_{inf} = \frac{Q_x \times T_{irrig}}{A_{wetted}}$$

- Where: D_{inf} = The depth water infiltrates
- Q_x = Average flow per emitter
- T_{irrig} = Duration of an irrigation event
- A_{wetted} = Wetted area per emitter

Equation 23: Equivalent applied depth (drip-micro)

$$Dz_{app} = \frac{Q_x \times n_e \times T_{irrig}}{A_{plant}}$$

- Where: Dz_{app} = Applied depth in a given zone, z
- Q_x = Average flow per emitter
- N_e = Number of emitters per plant
- T_{irrig} = Duration of an irrigation event
- A_{plant} = Ground area per plant

Equation 24: Instantaneous application rate (R_{it})

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

Where: R_{it} = Instantaneous application rate for transect i (mm/h)
 \bar{D}_i = Mean application depth applied to strip width at transect i (mm)
 A_w = Wetting area of distribution system (m)
 V_i = Mean travel speed of the distribution system at transect i (m/h)

Equation 25: Instantaneous application rates – linear move (R_{il})

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

Where: R_{il} = Instantaneous application rate (mm/hr)
 W = Wetted width (diameter) of nozzle pattern (m)
 Q_m = Machine discharge (L/s)
 L_e = Effective length of lateral (m)

The constant 3,600 assumes that the peak application rate is about 4π that of the average application rate if the application rate pattern is elliptically shaped (CPD).

Equation 26: Instantaneous application rates – centre-pivot (R_{ip})

$$R_{ip} = 9,170 \left(\frac{Q_f}{r_e^2} \right) \frac{r}{W}$$

Where: R_{ip} = Instantaneous application rate at radius, r (mm/hr)
 r = Radial distance from pivot centre to point under study (m)
 W = Wetted width (diameter) of nozzle pattern at r (m)
 Q_f = Discharge for the full irrigated circle (L/s)
 r_e = Effective radius of the full irrigated circle (m)

The constant 9,170 assumes peak application rate is about 4π the average application rate if the application rate pattern is elliptically shaped (CPD)

MISCELLANEOUS EQUATIONS

Equation 27: Well flow-drawdown relationship

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

$$DD = K_d Q^x$$

Where: DD = Well drawdown
 K_d = Discharge coefficient
 Q = Flow rate
 x = Well exponent

Equation 28: Hazen Williams formula

$$H = \frac{1.213 \cdot 10^{10} \times Q^{1.852} \times L}{C^{1.852} \times D_h^{4.871}}$$

Where: Q = Flow (ℓ/s)
 L = Length of pipe(m)
 C = Hazen Williams roughness
 D = Pipe internal diameter (mm)

For very rough, rusty situations, use a $C = 100$.

For moderate, average conditions, use a $C = 120$.

For smooth situations, use a $C = 140$.
