IRRIGATION
NEW ZEALAND
TECHNICAL & TRADE

The New Zealand Piped Irrigation Systems Design Code of Practice

Contents

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NOTE: This Code is paired with the *The New Zealand Piped Irrigation Systems Design Standards* and *The New Zealand Piped Irrigation Systems Evaluation Code of Practice.*

Ministry for Primary Industries
Manatū Ahu Matua

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Introduction

Purpose

The purpose of the Code of Practice is to provide a consistent practice guide for designers of piped irrigation systems in New Zealand. It provides a general design approach with items that must be considered when planning, designing, and implementing a new irrigation development. It describes irrigation performance indicators, and a description of how they fit into the design process.

It is expected that designers will follow the general design process outlined in the Code of Practice, but many will have their own specific procedures. The Code of Practice should be used primarily to ensure that all of the main design aspects have been considered.

The Code of Practice is intended to be used in conjunction with *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012). The design standards provide specific performance values which must be achieved by all systems. Any deviation from these must be explained to the purchaser of the irrigation system.

The New Zealand Piped Irrigation Systems Design Code of Practice (INZ, 2012) and *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012) are part of a suite of documents which should be used in conjunction with one another. The other documents include:

- *The New Zealand Piped Irrigation Systems Installation Code of Practice* (INZ, 2012)
- *The Standard Irrigation Contract* (INZ, 2012)
- *The New Zealand Piped Irrigation Systems Evaluation Code of Practice* (INZ, 2010)
- *Irrigation development checklist* (INZ, 2013)

The design process described in the design guidelines and the performance indicators and values contained in this document are intended to be applied to agricultural irrigation systems. They do not amend or replace other industry, performance indicators, guidelines, codes of practice or standards.

Audience

The Code of Practice is intended for designers of piped irrigation systems. This may include engineers, equipment suppliers, and specialist irrigation designers.

It is envisaged that the Code of Practice will be referenced when assessing the performance of installed irrigation systems.

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. In general, irrigation has been highly successful and has driven agricultural intensification in the drier areas, improving and sustaining the general well-being of rural communities.

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
- 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 system owners to lift the level of economic and environmental performance.

Irrigation New Zealand, in consultation with its stakeholders and as part of its mission to promote excellence in irrigation, has initiated the development and review of this irrigation design Code of Practice and the associated design standards.

Intent

The Code of Practice is intended as an industry best practice guideline. Designers should interpret it according to the requirements of individual properties and owners. All decisions made must also comply with statutes, regulations, and other legal requirements and industry standards.

What is not in this document

The Code of Practice applies only to the design of piped irrigation systems. It does not cover:

- Surface water irrigation methods
- Design of surface water structures (e.g. races or ponds)
- Irrigation equipment manufacturing or quality standards
- Installation or commissioning of irrigation systems
- Performance evaluation of irrigation systems

Those activities should be guided by the relevant existing codes of practice, including:

- *The New Zealand Piped Irrigation Systems Installation Code of Practice* (INZ, 2012)
- *The New Zealand Irrigation System Evaluation Code of Practice* (INZ, 2010)

This document is not a design manual and does not provide sufficient information for designers intending to work outside of their current area of expertise.

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Irrigation system performance indicators

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

Irrigation system design performance indicators provide a measure of system performance and its potential impacts on the environment, on-farm economics, productivity, and labour. The performance characteristics should provide designers and purchasers of irrigation systems with a quantifiable measure of the system, and enable performance comparisons with industry benchmarks and with other systems to be made.

The performance characteristics cover six areas of measurable performance, as follows:

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

Design performance characteristics can be both inputs into the design process and measurable outputs. For that reason, they have been divided into basic design parameters (Table 1) and performance indicators (Table 2). Irrigation designers should provide the following to the purchaser in the design report or quotation:

- The parameters that have been used for the design
- The performance indicator values that will be achieved using this design if the specified equipment is installed correctly
- Details on what to measure and where, for the purchaser or a third party to verify that the system is achieving the system performance indicator values

Specific base information needs to be available (or measured) to allow the indicators to be calculated. In addition to the system performance values themselves, the information used to calculate the indicators, as described in Table 1 and Table 2, must also be provided to the purchaser.

Table 1 Design parameters

Base design parameters	Unit(s)	Associated information
	Water Use Efficiency	
System capacity (based on 24 hour delivery)	ℓ/s/ha or mm/day	• Flow rate of irrigation system • Irrigated area • Actual hours of pumping per day
Soil water holding capacity in crop root zone	mm	• Soil profile available water • Type of crops to be grown • Crop root depths
Management allowable deficit (MAD), also known as refill point, trigger point or stress point)	mm or %	• Soil available water holding capacity in crop root zones • Allowable soil water depletion for relevant crops
Assumed application efficiency	%	• DU • Applied depth
Minimum return interval	days hours	• System capacity • Application depth • Application efficiency
Maximum allowable design application intensity	mm/hr	• Gross depth of water applied • Time (hours) taken to physically apply water
Target application uniformity	%	• CU • DU, CV
Design life	years	• Decided in consultation between Grower and Designer

Table 2 Performance indicators

Performance indicator	Unit(s)	Associated information
	Water Use Efficiency	
System capacity (based on 24 hours)	ℓ/s/ha mm/day	• Flow rate of irrigation system • Irrigated area • Actual hours of pumping per day
Ratio of design system capacity to actual system capacity	%	• Design system capacity • Actual system capacity
System application depth range	mm (range)	• Gross depth of water able to be applied
Ratio of applied depth to management allowed deficit (MAD)	%	• Application depth • Management allowable deficit (soil parameter, discussed in Section 2.3.3)
Return interval	days hours	• Return intervals physically able to be achieved with each system type
Average application intensity	mm/hr	• Gross depth of water applied • Time (hours) taken to physically apply water
Ratio of application intensity to soil infiltration rate	%	• Intensity of water application • Soil infiltration rate over watering time • System type
Application uniformity	%	• CU • DU, CV
Adequacy of irrigation	ratio	• The ratio of the mean low quarter depth applied, to the mean target depth required across the field as a whole.
Potential application efficiency	%	• The single event potential application efficiency estimated from field distribution
Distribution efficiency	%	• Water supplied to the property • Water discharged to the application system
Hydraulic efficiency	%	• Pressure loss through the mainline net of elevation differences
Headwork efficiency	%	• Pressure loss through headworks components net of elevation differences
	Energy Use Efficiency	
System energy rating	kW	• Size of pumps in kW
Pump system efficiency	%	• Pump system efficiency % (pump efficiency * motor efficiency)
Energy per hectare	kW/ha	• Size of pumps in kW absorbed • Total area of land service by that pump
Energy per unit volume	kWh/m3	• Volume of water pumped • KWh of energy used
	Labour Efficiency	
Labour hours per hectare irrigated per year	hr/ha/yr	• Time spent on operating and maintaining irrigation system • Effective area irrigated
Hours per mm applied	hr/mm	• Time spent on operating and maintaining irrigation system • Seasonal depth of water applied

	Capital Efficiency	
Capital cost	\$/ha \$/ℓ/s	• Total cost of irrigation system • Effective area irrigated • System flow rate
Operating cost	\$/ha/yr \$/m^3	• All running costs of irrigation system (excl cost of capital) • Effective area irrigated • Volume of water used per season
Total annual cost	\$/ha/yr \$/m^3	• Annualised capital cost per hectare (based on stated financial assumptions incl cost of capital) • Annual operating cost per hectare
	Environmental Performance	
Irrigation system efficiency	%	• Water supplied to the irrigation system • Water stored in root zone
Drainage index	m^3/ha/yr	• Volume of water draining through profile • Area irrigated (ha)

See the "Definitions" section (page 27) for further explanation of what each of these performance indicators means.

See Appendix B for a description of how to calculate each of these performance indicators.

The New Zealand Piped Irrigation Systems Design Standards (INZ, 2012) provides further discussion around specific performance indicators and the minimum required values for each.

The irrigation system design process

Process overview

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

1. Gathering information
2. Deciding performance parameters
3. System design
4. Final specification and quotation

In the *"gathering information"* stage, the needs of the purchaser and any issues that need to be considered before significant resources are committed to the project are determined. A site visit is conducted, and the basic input parameters needed to complete the design are collected.

In the first part of the design process, *"deciding performance parameters"*, a design specification is prepared. This details all of the things the irrigation system must be able to achieve. It prescribed performance characteristics such as application depths and return intervals.

"System 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.

A *"final specification and quotation"* are then prepared. These describe to the purchaser what the system will look like and how much it will cost. It includes a description of the hardware, costs for supply and installation, as well as the performance values to be achieved by the system to be supplied.

Contracting, construction, testing, and commissioning of the irrigation system is covered in detail by the *The New Zealand Piped Irrigation Systems Installation Code of Practice* (INZ, 2012).

The following sections of this document describe each of the steps in the design process in more detail.

1 Gathering information

The first stage in the development of an irrigation system is to gather the necessary site-specific information needed to complete a design. This information includes the layout of the farm, water supply information, soils information, climate information, regulatory requirements, and farm management needs.

Much of this information will already be held by the purchaser, and should be gathered together prior to consultation with an irrigation system designer. However, it is the designer's responsibility to verify that the information provided by the purchaser is accurate – this is often done during a site visit.

1.1 INITIAL PREPARATION BY THE PURCHASER

The first step for a prospective purchaser in developing or upgrading an irrigation system is to carry out an initial investigation so that commitment of capital and other resources can be justified.

Prior to beginning a new irrigation development or upgrade, the purchaser should:

- Consider the likely availability of a water supply
- Gather information to support water consent applications
- Consider compliance with any regulatory requirements
- Consider issues related to intensification of land use
- Conduct an economic analysis (often carried out by an independent advisor)
- Gather information to support applications to financiers
- Assess labour availability
- Collect details required by the designer of the irrigation system

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 common 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.

The *Irrigation Development Checklist* is available to guide the purchaser through the gathering of information required to calculate the design inputs, recognise which type of system best suits their requirements and specifications on which to base the purchase decision.

1.2 INITIAL CONSULTATION WITH THE DESIGNER

The purchaser should contact an irrigation firm or independent designer to initiate the design and supply of an irrigation system.

Prior to starting an irrigation design, the designer should:

- Establish the purchaser'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
- If the client wishes to progress the investigation, arrange for a time to meet on the property

The designer should not:

- Promise something that cannot be delivered
- Force or coerce the purchaser into making decisions against their will
- Attempt to sell a system that clearly will not meet the needs of the purchaser
- 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

1.3 PROPERTY VISIT

Having obtained sufficient information from the client to ensure that further investigation is warranted, the designer should visit the property to obtain the necessary details to complete the design.

Table 3 provides a list that should be discussed and the necessary information obtained during the property visit, much of this information should be gathered by the potential irrigator prior to contacting an irrigation designer. The purchaser may need to consult a number of specialists including soil scientists, water supply experts, water quality laboratories etc. Some of these specialists may cost the purchaser to gather information, however the better the purchaser understands the inputs required for the design of a system then the better the system will meet his expectations.

Table 3 Items to be discussed during the property visit

Item	Decription
	Site Layout
Map	Obtain a copy of the property map, including all current infrastructure and land features.
Existing irrigation	If present, determine how well it performs, its limitations and items to be aware of when upgrading or adding new irrigation.
Topography	Identify land features that may affect the design of the irrigation system, including land slope, hills, gullies, waterways, flood risks, etc.
Design area	Identify the areas that the purchaser would like to irrigate. This should be revised as the rest of the information in this table is gathered.
Fencing	Identify existing or potential fencing arrangements, and discuss the purchaser's preferences around relocating these, if necessary.
Shelter	Identify the natural or artificial wind breaks that are present or will be required.
Land restrictions	Identify protected areas or covenants on titles, and the location of any sensitive areas.
Energy sources	If power is required, locate the nearest supplies and identify any limitations.
Vandalism	Identify any potential for vandalism.
	Water Supply
Water supply location	Identify the location of existing water supplies, or potential locations for future water supplies.
Water quantity	Identify how much water is available, both in terms of flow rate and total volume per season.
Water supply reliability	Determine if water restrictions are a problem that may require water storage or extra capacity in the irrigation system for "catching up".
Water quality/chemistry	Determine if water quality is physically and chemically suitable for the proposed irrigation development.
	Soils Information
Soil type	Identify the types and locations of the soils on the property.
Available water holding capacity	Determine the depth of water that is available to plants.
Effective crop rooting depth	Determine the depth from which roots extract water from the soil.
Management allowable deficit (MAD)	Determine how dry the soil can become before it requires watering.
Infiltration rate	Determine the rate at which the soil absorbs water without ponding. This may be affected by other soil features such as pans, drains, or stock treading.
Drainage	Identify any areas with poor or enhanced drainage. This may include natural or artificial soil drainage.
Variability	Assess the likely variability of soil properties across the property.

Item	Decription
	Climate Information
Rainfall	Obtain rainfall records for the property, or from the nearest weather station.
Evapotranspiration	Obtain evapotranspiration-related parameters for the property.
Wind	Determine the prevailing wind directions and normal wind speed for the property.
	Regulatory Requirements
Resource consents	Check that all necessary resource consents have been obtained. Identify the requirements for the irrigation system stipulated by the consent.
Nutrient requirements	Ensure that on-farm nutrient limits with respect to application of fertilizers and leaching requirements are obtained and understood.
District and regional council requirements	Find out whether there are any district or regional council requirements, in addition to resource consents, necessary.
	Farm Management Information
Animals	Determine if any stock will be grazed in the irrigation areas. If so determine what type and how many?
Crops	Identify the types of crops to be in the short- and long-term. Determine if crop contracts impose any conditions with respect to irrigation?
Other water needs	Determine if water is required for other purposes (e.g. stock water, fruit cooling, frost protection, leaching of salts, processing, dairy use)?
Labour	Determine the skill level of the labour available to operate the system.
Future flexibility	Identify the likelihood and timing of future changes (e.g. an expansion of the irrigated area).
Risk preference	Determine how much risk of not meeting demand the purchaser is prepared to accept.
System type	Determine if the purchaser has any preference for irrigation system types.
Process Control	Identify the purchaser's preferences for automated checks and controls.
Price limits	Determine what the purchaser's limitations are on how much money they are prepared to spend.
Delivery	Determine the date by which the system must be operational.
Health & Safety	Identify any health and safety issues pertinent to the site.
Other	Identify any other issues relevant to the purchaser.

1.3.1 Site layout

Information about the layout of the farm is necessary for siting infrastructure (e.g. intake structures, pipelines) and identifying priority irrigation areas. Information gathered prior to the design of an irrigation system can help identify any site restrictions or potential logistical limitations (e.g. topography, proximity to power lines).

This information is often best obtained during a farm visit.

1.3.2 Water source

Without a reliable water source, an irrigation system is worthless; yet many irrigation systems are designed, purchased and installed without water being available.

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.

Regulatory requirements

Purchasers should ensure that all relevant regulatory requirements, particularly resource consents and their conditions, are provided to designers.

Irrigation designers must meet the following requirements:

- Be familiar with regional council and local council requirements with respect to irrigation
- Where resource consents have been obtained, obtain a copy of them, and ensure that the relevant necessary equipment is supplied and installed so that the purchaser can meet the conditions of it

Water access issues

Any uncertainties in gaining access to water, and any requirements for gaining access (e.g. easements), should be discussed prior to beginning any irrigation design.

In the case of groundwater, some common factors to consider include:

- Obtaining consents
- Consent conditions
- Bore location
- Bore diameter
- Well driller availability
- Likely yield
- Interference effect on, and of, neighbouring bores on drawdown

Where a well or bore has already been drilled, the designer must obtain accurate, reliable information on bore construction and bore performance before designing an irrigation system.

If a bore has been drilled and standing idle for more than 12 months, or possibly has been disturbed in some way such that the water supply could be at risk (well cap not secured for example), the designer must recommend that the bore be checked and retested.

In the case of surface water takes, some common issues include:

- Location of the intake (i.e. Limited access)
- Intake design
- Method of conveyance (e.g. canals, pipes)
- Turnout design

If water is from a community scheme, access and cost of water, and any specific scheme requirements must be considered.

Quantity of water physically available

The quantity of water available is often limited for some or all of the irrigation season. For example:

- Bore yields may be limited
- Scheme or regulatory restrictions may apply
- Seasonal volumes
- Interference effects
- There may be reduced flows in the source streams
- Groundwater levels may change
- The volume of water stored in dams may run low

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 some ability to 'catch-up', thus minimising the effect of shortfalls, or to build in extra capacity in pumps to lift water from greater depths.

Quality of water available

Consideration of the quality of the water to be used for irrigation is particularly important in systems with small discharge orifices. There are five types of plugging in drip/micro systems which may require chemical treatment.

- Slimy bacteria
- Iron and manganese oxides
- Iron and manganese sulphides
- Calcium and magnesium carbonate precipitation
- Root intrusion into buried emitters

Water to be used in drip/micro irrigation systems should be tested for suitability and the appropriate chemical injection equipment specified to treat any likely problems.

1.3.3 Soils Information

Soil information for the proposed irrigated area must be obtained to ensure that the irrigation system is designed to match on-site conditions. Knowledge of the soil parameters listed in Table 2 is necessary for calculating an appropriate irrigation application depth, application intensity, and return interval.

Regardless of the method of determination, soil properties should always be verified on-site, or with the farmer or another local expert. As a minimum, soil textural properties and effective rooting depth must be determined on site.

To determine soil properties:

- Take soil samples and/or measure the necessary parameters, or
- Refer to soil maps and soil property information for the region (e.g. From regional councils, or landcare research soils portal)

Total available water (TAW)

Use local soil information to determine the soil's Water Holding Capacity (WHC). WHC is used to calculate the required application depth and return interval for an irrigation system. This may be done by adjusting local soil WHC values for plant rooting depth.

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

Determine the effective crop root depth (D_r) and adjust the soil WHC accordingly:

$$\textit{Total Available Water} = \textit{WHC} \times D_r$$

For soils with distinct layers (e.g. silt loam over stones), sum the water holding capacities according to the depth of each layer.

Effective crop root depth

Use the average effective root depth (D_r) to adjust the values for WHC, as discussed above. Values determined on-site must be used. Bear in mind that soil conditions on site may limit root depth and site specific situations need to be determined. Consideration for crop rotations is required to ensure the correct rooting depth is applied during the design process.

Crop factor

The crop factor (*cf*) should be used to define the peak demand of the particular crop being grown. This coefficient changes throughout the growing season, because the crop does not cover the entire ground surface for a portion of the lifecycle of the crop. This is an issue for scheduling irrigation and design should cater to the water demand of a full canopied crop, so plant-specific information is desirable.

The crop factor is used to calculate an appropriate return interval for the crop (see Section 2.6). Crops with a lower cf may be okay with longer return intervals because they transpire water more slowly than plants with a higher *cf*.

Critical deficit

Critical deficit (sometimes referred to as Maximum allowable deficit) is a measure of how much soil moisture deficit may develop before crop stress occurs. This is also known as the "stress point" or "maximum allowable deficit". Designers use critical deficit to calculate appropriate application depths and return intervals. The percentage depletion allowed is dependent on the evapotranspiration rate (ET). The larger the ET, the smaller the percentage of depletion allowed.

Soil infiltration rate

The range of soil infiltration rates likely to be experienced must be determined for each soil type encountered. Use site-specific information wherever possible, as infiltration rates can be highly variable between (and even within) properties, even for similar soil types. For example, the infiltration rates of well-structured irrigated soils may be considerably higher than on previously un-irrigated soils. Alternatively, the infiltration rate of a compacted soil, or soils with a surface crust, may be significantly lower than other soils of a similar type that are not compacted or crusted.

1.3.4 Climate

Obtain information about the local climate (i.e. rainfall, evapotranspiration, prevailing wind direction) to ensure that the irrigation system is designed to match on-site conditions. Knowledge of the climate parameters listed in Table 3 is necessary for calculating irrigation demand and for designing a system to suit.

The best irrigation designs are based on a detailed irrigation demand analysis. This will often include an assessment of historical climate data to:

- Identify high irrigation demand periods
- Determine the peak system flow rate
- Determine the volume of irrigation water required to meet demand in most seasons (e.g. 9 out of 10 years)

Climate information may be obtained from:

- Climate maps of the region (e.g. maps from the regional council)
- A local weather station or on-farm weather recorder,
- NIWA's Virtual Climate Station Network, or
- Local expert advice (i.e. from someone who has specific knowledge about the climate in the area)

Always use the most accurate, relevant sources of information available.

1.3.5 Farm management information

It is important that the irrigation system fit in with the management of the rest of the farm operations. Ensure that farm management needs are identified prior to designing an irrigation system. See Table 3 for some examples of things that should be considered.

Wherever possible, it is recommended 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, 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 to come. This should be discussed with the purchaser.

A design must consider the purchaser's current needs, and any additional needs into the foreseeable future. For example, if any expansions to the irrigation system are planned, it is best to accommodate this within the current design wherever possible.

A good design will strike a balance between capital investment and on-going operational costs. Each purchaser is likely to have their individual preferences in this matter.

A design must also consider the logistical needs of the purchaser (e.g. when does the system need to be operational, and what level of labour input is required?).

1.4 DECIDING HOW TO PROCEED

The first stage in the development of an irrigation system is to gather the necessary site-specific information needed to complete a design. This information includes the layout of the farm, water supply information, soils information, climate information, regulatory requirements, and farm management needs.

Much of this information will already be held by the purchaser, and should be gathered together prior to consultation with an irrigation system designer. However, it is the designer's responsibility to verify that the information provided by the purchaser is accurate – this is often done during a site visit.

Once all the information necessary to complete an irrigation design has been gathered, a decision is required as to how best use the information.

2 Deciding performance parameters

The second stage in developing an irrigation system is to determine the level of performance of the future system. Both the designer and the purchaser should be involved in this process.

Particular attention should be given to:

- Deciding on an appropriately sized and located area of land to irrigate
- Deciding on an appropriate rate of irrigation (system capacity)
- Choosing application depths and return intervals that match soil water holding properties
- Choosing an application intensity that matches soil infiltration rate
- Meeting the requirements of resource consents
- Meeting the requirements in *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012) relevant to the system performance indicators, and
- Meeting the needs of the purchaser in terms of labour, energy, and cost efficiency

2.1 IRRIGATION AREA

In many cases, the amount of land that may be irrigated will be limited by the amount of available water, and land physically able to be developed.

In general, the most suitable areas for development are those that:

- Will achieve the greatest increase in production with the addition of irrigation water
- Are located close to the water supply
- Are at the lowest elevation
- Have well drained soils
- Are flat, and
- Have dimensions suited to the available irrigation equipment

Irrigation areas may be chosen by the purchaser, or the designer may be asked to provide advice. The best irrigation designs are based on a detailed analysis of the available options, and should aim to irrigate the greatest land area for the greatest benefit.

If enough water is not available to irrigate the desired land area, the irrigation area may need to be reduced. Or, if the purchaser is not averse to some risk, the full land area may be irrigated at a reduced rate. The consequences of this type of decision should be discussed with the purchaser prior to proceeding.

2.2 SYSTEM CAPACITY

When designing the irrigation system for a particular property, consideration must be given to the entire farming system as well as future uses for the irrigation system. Crop rotations must be considered and the capacity of the irrigation system such that water applied will meet the times of greatest demand.

The irrigation system will ideally be designed to meet the peak water demand of each crop irrigated within the design area. In practice, the peak demand will normally be based on a likely frequency of demand (i.e. 1-in-10-year mean 7-day demand) that should be agreed with the purchaser.

The system capacity (W) is usually presented in units of mm/day or l/s/ha, and should be determined by taking account of the following factors:

- Water availability/reliability
- Rainfall and evapotranspiration – crop demand
- Soil characteristics
- Crop type
- Irrigation system efficiency
- Requirements for leaching
- The level of risk the purchaser is prepared to take in not meeting peak demand

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

2.3 DESIGN FLOW RATE

System capacity is based on a 24-hour per day supply.
The design flow rate (Q) must be determined taking into account the following:

- System capacity
- Area irrigated
- Hours of operation per day
- The physical ability of the irrigation system to utilise the available hours

If the available water supply flow rate is insufficient to irrigate the desired land area, adjustment to the design parameters will be required. These could include the following:

- Reducing the irrigated area
- Allowing for a higher risk of not meeting demand – spread the water more thinly
- Increasing the hours of operation per day
- Using buffer storage to increase on-farm flow rate (where water supply flow rate is less than design flow rate)

The consequences of this type of decision must be discussed with the purchaser prior to proceeding.

2.4 GROSS APPLICATION DEPTH

The maximum application depth depends primarily on the soil water holding capacity, the crop rooting depth, and the water extracting capability of the plants being grown.

The gross design application depth (Dg) should not be greater than the TAW, adjusted for the MAD

$$D_g \leq \frac{TAW \times MAD}{100}$$

Where:

D_g	is the gross application depth (mm)
TAW	is the total available water (mm)
MAD	is the management allowable deficit (%)

A range of appropriate application depths should be specified for each different soil and crop type so that an irrigation system capable of meeting the needs of each may be selected.

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. If not already accounted for in the determination of system capacity, the leaching requirement should be added to the gross depth of application to determine total application depth, which will need to be accounted for in delivery flow rates.

Where potential contaminants are present (e.g. in systems with fertiliser injection, or in areas exposed to effluent application), extra care is required to select an application depth that avoids leaching.

2.5 NET APPLICATION DEPTH

If application efficiency was accounted for in the determination of system capacity and flowed through into the depth calculations, the gross depth of application can be continued to be used.

If application efficiency was not accounted for in the determination of system capacity, the net application depth must be used to determine return intervals.

$$D_n \leq \frac{\text{Gross application depth (mm)} \times \text{application efficiency (\%)}}{100}$$

Designers should make it clear to the purchaser and in their documentation how they have treated application efficiency and the effect it has on application depth and return intervals.

2.6 RETURN INTERVAL

The return interval (*Ir*) or frequency of irrigation is selected to ensure that the irrigation system can maintain soil moisture at an adequate level to avoid plant water stress. The minimum required return interval is normally calculated after the (net) application depth and system capacity are known:

$$I_r \leq \frac{D_n}{W \times f}$$

Where:

I_r	is the return interval (days)
D_n	is the application depth (mm)
W	is the system capacity (mm/day)
f	is the crop factor

Other methods for calculating an appropriate return interval may be used, where appropriate (e.g. daily water balance methods).

2.7 APPLICATION INTENSITY

In general, irrigation systems should be selected so that the application intensity of the system does not exceed the infiltration rate of the soil over the length of time the water is applied. If this cannot be achieved, designers should identify when or where the application intensity is likely to exceed infiltration rate and explain the consequences of it happening.

On flat land, it is often adequate to ensure that the average application intensity (*Ra*) of the system does not exceed the infiltration rate of the soil. On sloping land, consideration must also be given to the instantaneous application intensity (*Ri*). If surface runoff is to be avoided on sloping land (>5% slope), *Ri* should also not exceed the infiltration rate of the soil.

Adjustment for application duration

Different application intensities are appropriate for applications of different durations. The infiltration rate of soil generally decreases with time, so higher application intensities are appropriate for shorter applications, while lower intensities are required for longer applications.

This means that a range of application intensity-duration combinations will be suitable on a given soil. The irrigation system designer must ensure that the *Ra* or *Ri* (whichever is applicable) of the chosen irrigation method will fit within these criteria. Application intensity must not exceed the soils infiltration rate or ponding and runoff could occur.

Adjustment for land slope

If the land is sloping, the design *Ra* value must be reduced.

How to calculate application intensity
Appendix B includes equations for calculating *Ra* or *Ri* for different irrigation methods. Designers should make these calculations, at the following locations:

- 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
- For sprinklers operating in a fixed grid, with acceptable overlap formulae

2.8 OTHER PERFORMANCE TARGETS

Other aspects of system performance, such as application efficiency, should be considered as early in the design process as possible. The designer should set targets for each of the system performance indicators listed in Table 2, prior to proceeding through the detailed system design. These targets should be discussed with the purchaser to ensure the proposed system will meet the purchaser's needs.

Refer to *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012) for further discussion of the irrigation Performance Indicators, and the minimum required values for each.

Effective Water Use
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 (Ea) is 76%.

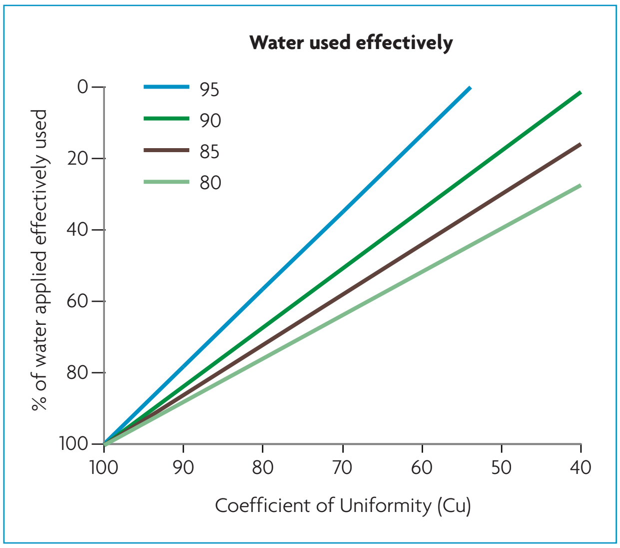

Figure 2. Effective water use for a range of CUc's.
The four lines represent the percentage of irrigated area that is designed to be fully replenished.

3 System design

3.1 IRRIGATION SYSTEM SELECTION

An irrigation system type should be selected that is capable of meeting the performance targets. It should also meet as many of the purchaser's other expectations in terms of;

- Ease of operation
- Reliability
- Acceptable public perception
- Maximising production of 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 needs, and that the choice is justified. This dialogue is important to prevent inappropriate system types from being sold to clients when there is doubt that they will deliver the expected performance.

If the performance of the selected system is significantly different from the 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 intensity at the end of a centre-pivot may cause surface redistribution and surface runoff, which will reduce application efficiency. The significance of this should be explained to the purchaser, ideally in terms of production. The approximate cost of reducing application intensity and the expected benefits should be estimated.

General layout
Ideally, the property should be designed 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 any site-specific constraints, as discussed during the initial property visit (see Table 2).

System performance Indicators
The selected irrigation system should be compared to the target performance values to ensure that the system matches the soil-climate system at the property, and that it meets the needs of the purchaser.

Stream impact energy
The breakdown of soil particles at the soil surface may be a problem with high-volume sprinkler irrigation. The impact of the irrigation water on the soil particles can cause 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, or to avoid irrigating on particularly sensitive soil types. Designers should:

- Identify potential problems with stream impact energy
- Select an irrigation system type to minimise or eliminate problems with stream impact, where appropriate, and
- Make any potential problems and proposed solutions known to the purchaser

3.2 SPRINKLER OR EMITTER LAYOUT

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 or emitter spacing, nozzle size and operating pressure should be selected to provide the desired application depth, intensity, and uniformity.

In general, designers should consider the following when designing the layout of sprinklers or emitters:

- 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
- Travelling irrigators and linear move systems should preferably be designed to operate in straight rows
- Design for larger application depths, low application intensities, and fewer shifts with labour intensive systems (subject to soil suitability)
- Design for smaller application depths, higher application intensities, and more shifts on automated systems
- Use smaller, more closely spaced nozzles whenever practical
- If practical, design systems so that sprinkler laterals or lines are oriented so that prevailing winds flow across them

3.2.1 Spray irrigation

Manufacturer's coefficient of uniformity (CU_c) or lower quartile distribution uniformity (DU_{lq}) data should be used to select the optimum sprinkler type, spacing, nozzle size and operating pressure ranges.

If manufacturer's CU_c or DU_{lq} data is not available for the required sprinkler spacing and operating pressure, designers should determine them using appropriate sprinkler overlap software or formulae. Standard formulae for calculating CU_c and DU_{lq} are given in Appendix B.

The design application uniformity must comply with the requirements listed in *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012). If site constraints dictate the need for a system with lower uniformity, the designer must clearly explain the on-going energy, water use, crop growth, and cost implications to the purchaser.

All sprinkler manufacturers have sprinkler selection software which allows calculation of CU_c and DU_{lq} values at different sprinkler spacing. CU_c and DU_{lq} figures are essential system performance indicators and every effort should be made to present these figures with the design to the purchaser.

Sprinkler spacing and application uniformity should be adequate for potential future uses, as well as immediate needs. For example, if the purchaser is considering the application of chemicals or waste water through the system, higher application uniformity may be required.

3.2.2 Micro-sprinkler and drip irrigation

The minimum design emission uniformity (EU_{des}) is used to calculate the expected flow variation within drip or micro-irrigation systems. This is then used to calculate the allowable pressure variation to guide the hydraulic design of the system.

Manufacturers of micro-sprinklers or drippers should also supply coefficient of variation (Cv_{man}) values for their products so designers can determine the allowable design parameters.

Equations for calculating EU_{des} and Cv_{man} are described in Appendix B.

3.2.3 The effects of wind

Sprinkler irrigation systems are often affected by wind. Wind losses may be reduced by not irrigating in excessively windy conditions, or selecting an irrigation type that is less affected by the wind. Designers of spray irrigation systems should take into consideration the frequency and direction of prevailing winds when orienting and spacing emitters.

The use of single jet, low angle sprinklers may help improve performance in windy conditions. Designing for lower operating pressure and larger droplet sizes can also help by increasing the average droplet mass and decreasing throw distance. However, these types of system modifications will likely cause greater droplet impact energy, and may increase problems with infiltration and surface runoff.

Watering rectangular fields with circular application patterns can cause watering outside of irrigated areas. To reduce or prevent this, control of the pattern is required (e.g. by using part circle sprinklers), or some areas of the field may need to be left un-watered (e.g. the corners).

3.2.4 The consequences of poor 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 uniformity is likely to cause:

- Over-watering in some areas
- Under-watering in some areas

- Losses of water to drainage in over-watered areas
- Losses of production in under-watered areas
- Surface redistribution, which can amplify the other effects of poor uniformity by further over-watering low spots and under-watering high spots in the topography

The effects of poor uniformity may be difficult to detect, as many of them occur below-ground. In extreme cases, reductions in yield become apparent in under-watered areas. However, detecting overwatering due to poor uniformity, especially if average application depths and application rates are correct, is problematic.

Some common reasons for poor uniformity of sprinkler irrigation systems include:

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

Some common reasons for poor uniformity in drip/micro irrigation systems include:

- Blockages
- Pressure variations in the system
- Effect of wind on micro sprinkler distribution patterns

3.3 HYDRAULIC DESIGN

In general, an irrigation system that is well hydraulically designed will:

- Provide adequate pressure and flow rate to each irrigation outlet
- Minimise required operating pressure of the pump
- Minimise installation cost, and
- Minimise energy consumption

The hydraulic design should take into consideration:

- Flow velocities through pipelines
- Elevation changes across the property
- Friction losses through pipelines, fittings, and other in-line components
- Soil conditions for buried pipelines
- Environmental conditions for surface pipelines
- Longevity of all components
- Capital costs, and
- System operating costs

4.3.1 Pipeline layout

In addition to the general hydraulic design requirements, the pipeline should be laid out in such a way as to maintain an acceptable level of pressure loss. For main lines the shortest route possible between the pump and zone valves should be taken. Within zones, laterals should follow contour lines as closely as possible. If laterals have to run across contours then generally the submain branches should be placed two thirds of the way up the lateral so only one third of the lateral length is up hill from the submain.

3.3.2 Water velocity

Maximum water velocity

In theory, there are no hard upper limits on water velocity in pipes. However, the higher the velocity, the greater the risk of damage through surges and water hammer. This particularly applies to large diameter pipes subject to uncontrolled starting and stopping.

Using larger pipe results in a smaller water velocity for a given flow rate, but smaller pipe is often preferred for cost reasons. The designer should aim to strike a balance between water velocity and pipe cost. This is often done by designing as close as possible to the maximum water velocity prescribed in *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012).

If the operational water velocity will exceed the Standards, 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, such as controlling filling rates or using higher class pipe.

It is possible that some pipe types, such as continuously welded polyethylene pipe, may be able to operate safely at a high water velocity. This is acceptable, provided that:

- The manufacturer of the pipe allows higher velocities to be used
- Warrantees and guarantees are not violated
- Protection is provided to prevent damage due to surges and water hammer, and
- The pressure requirements of the system are met

Minimum water velocity

A minimum operational water velocity must be maintained in order to flush sediment and solids through the system. *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012) lists the minimum water velocity required for different situations.

3.3.3 Pressure variation

The irrigation system should be designed to minimise pressure variation between water outlets. This should be done by carefully choosing the location of outlets or by sizing pipes for appropriate friction losses. If this is not possible, then additional components must be included to control pressure. Pressure regulators may need to be included on outlets, or some form of pressure regulation may be used at pumping stations (e.g. a variable speed drives).

It is important to consider on-going operational costs when designing methods of pressure regulation. Systems that require a lot of in-line pressure reduction are likely to be less energy efficient.

The design should specify a way to measure the pressure at each outlet. Pressure monitoring is discussed in more detail in Section 3.6.

3.3.4 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 0.4–1.5 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. Pipe deterioration often results in increased friction losses.

Designers should specify low friction valves and fittings, where appropriate.

3.3.5 Air and pressure relief

Air release

Air release valves must be specified in the design at the highest points in the pipelines.

For irrigation systems with long pipelines, at least one air relief valve for every 1,000 m of pipe is recommended.

For irrigation systems installed in undulating terrain, air release valves at all high points where air may build up is recommended.

At all times the designer should follow the manufacturer's recommendation regarding the sizing and installation of valves.

Pressure and vacuum relief

Pressure relief valves are recommended for situations where the pressure rating of the system (e.g. the pressure rating of pipes) may be occasionally exceeded.

Vacuum relief valves are recommended for situations where negative pressures may be experienced.

The design should specify if pressure or vacuum relief valves are necessary. It should also specify the type of valve to be used and the location in which it should be installed.

3.3.6 Surges and water hammer

All irrigation systems are susceptible to pressure surge or water hammer. Surges occur when the velocity of water within the system changes from a steady state condition to another. The most severe surges usually occur on starting and stopping pumps or instantaneous opening and closing of a valve in a pipeline.

Pressure surges may be high and can result in significant damage to piping, pumps and other components of the irrigation system. Designers should be aware that water hammer effects are always possible and may affect the design loads for the system.

Pipe route and the longitudinal profile of the pipelines may be influenced by water hammer implications.

Pressure surge calculations are complex and specialised engineering services may be required to analyse the proposed mainline design.

3.3.7 Thrust block design

Thrust blocks should be specified for each bend, valve, tee, reducer, dead end cap, and blank flange greater than 90 mm in diameter. Thrust blocks must be sized so that they provide the necessary support for the life of the pipeline and should be constructed out of concrete

Thrust blocks sizing will depend on:

- The pipe material and jointing method being used
- The expected operating pressure
- The soil in which the pipe is installed

Pipe suppliers provide design guidance for sizing thrust blocks including tables detailing the thrust on fittings and the bearing loads of different soil types. *The New Zealand Piped Irrigation Systems Installation Code of Practice* (INZ, 2012) also provides further information.

3.3.8 Filtration

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. 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 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 to use 80% of manufacturer's maximum flow rates through filters is recommended
- Other than pump intake screens, filters should never be installed on the suction side of a pump
- For self-cleaning screens, additional flow to clean the screens and discharge requirements must be included

The choice of filter element depends on what is to be filtered. Generally, grooved disks should not be used for organic matter or algae. A comparison of filter types and brands can be made by looking at the effective filter area.

For automatic back-flushing systems, also allow for potential damage due to water hammer and surge.

The New Zealand Piped Irrigation Systems Design Standards (INZ, 2012) provides further requirements for the selection of filters for irrigation systems.

3.4 PUMPING STATIONS

Many types of pumping systems are available, but usually only one or two will best match a design. 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 power required – this depends on flow rate and total effective head
- The speed of the pump – this may govern the type of drive employed (e.g. direct coupled electric, belt drive, diesel motor, etc.)
- Suction capacity – pumps are normally selected according to flow rate and operating head and then checked to see that the suction capacity is adequate
- The possibility of pumps running off the recommended operating range curve
- Consideration for servicing and cleaning

3.4.1 Selecting a pump duty

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 single or multiple pumps, or whether a variable speed drive unit or other control method 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 must be carried out for appropriate pump selection, and should include must include but not limited to:

- Friction losses through pipelines, fittings, and other in-line components
- Any lift from the water source to the pump
- Elevation changes across the property, and
- An allowance for wear and tear
- Outlet working pressure

Safety Margin
If the designer is selecting the pump, additional capacity to the calculated pump pressure and flow rate should be added as a precaution.

- Flow rate add 5–10% additional capacity
- Pressure add 5% additional capacity

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 injected abrasive fertilisers, these figures must be doubled.

3.4.2 Pump efficiency

Pumps should be selected so that they operate at or near their best 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.

It is usually more economical in the long term to select the most efficient pump, even if it requires spending a little more on the pump purchase. Using an oversized pump will ultimately result in higher operating costs, multiplied over the life of the system.

As a general rule, efficiencies for centrifugal pumps vary with flow rate, with smaller pumps being less efficient. It will therefore be more difficult to achieve a high pumping efficiency with smaller systems.

Pumps must be selected to operate at the best possible efficiency for majority of the time. If the pump is operating at any other efficiency point, the reasons and implications of operating at lower efficiencies must be made known to the purchaser.

3.4.3 Electric motor efficiency

Electric motors vary in their ability to convert electrical energy to the mechanical energy necessary to drive pumps. Differences in efficiency between standard motors are generally small (1–5%), but as the motor is at the power-supply end 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.

In general, large motors are more efficient than small motors, and standard motors will be more efficient than submersible motors. Also, 2-pole motors are generally more efficient than 4-pole motors (data not shown).

Because the efficiencies of surface mounted motors can be 5–10% higher than the efficiency of submersible motors, there may be energy advantages in using a combination of submersible and surface pumps for supplying water from deep wells.

High efficiency electric motors are increasing in availability, 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.

However, lack of appropriate motor control or inappropriate application can waste more energy than any motor efficiency consideration. 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.

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.

Small motors are usually inefficient so should be operated 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 often best to design systems to avoid peak loads.

3.4.4 Surface-mounted centrifugal pumps

In general, surface-mounted centrifugal pumps should be designed according to the following guidelines:

- The total suction lift for centrifugal pumps should not exceed 6.0–7.5 m, unless otherwise specifically allowed by the manufacturer (see discussions on suction lift, cavitation, and NPSH, below)
- Flexible couplings should be specified between pumps and rigid installations (suction or discharge) to prevent failure due to vibration
- A valve should be specified at the highest point on the pump casing to allow air to escape when priming the pump
- Some method of priming the pump should be specified

Suction lift

The amount of suction lift a pump can handle 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.

In general terms, the following should be considered relative to pump suction lift:

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

Design analysis must be carried out to eliminate problems associated with cavitation by avoiding:

- Lifting water from excessive depths
- Using pumps not designed for high suction lifts (high npsh requirements)
- Suction pipes that are too small or too long
- Inadequate submergence over the end of the suction pipe
- 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
- Leaks in the suction allowing air to enter, and
- Pumps running at low pressure and high flow rates (e.g. filling mainlines)

Net positive suction head available (NPSHA)

NPSHA depends on the particular system involved and will be affected by conditions such as altitude (atmospheric pressure) and temperature. To calculate the NPSHA at the pump inlet, add up the available pressure and subtract any pressure used up by losses prior to water arriving at the pump inlet:

NPSHA = Atmospheric pressure +/- any static head – friction head (including minor losses) – velocity head – vapour pressure of water at operating temperature

Note that the vapour pressure of water at 20°C is about 0.25 m.

Net positive suction head required (NPSHR)

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

To improve pump reliability, pumps should be selected and installed so that NPSHA is not less than NPSHR + 0.6 m, but as high as is practically and economically possible.

If the NPSHA is less than NPSHR + 0.6 m, the reasons for designing systems to a lower value and the consequences of a lower value must be explained to the purchaser.

3.4.5 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 designer must:

- Determine an accurate pump duty point, including allowances for pump drawdown in the well and fluctuations in groundwater level over time
- Ensure that the velocity of water in the rising column does not cause excessive friction loss
- Ensure that enough space is available between the pump and the well casing or use appropriately designed shrouds to allow for adequate cooling of the motor
- Column guides
- Access for measuring water levels

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 (increased drawdown) over the pump. If velocities are high and motors are long, the loss can be substantial.

The designer should calculate this friction loss and if significant, include in the design figures.

Pump cooling

Minimum velocities are specified by pump manufacturers to ensure that 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.

Designers must check that minimum velocities are maintained over the expected flow range of the pump. If a minimum velocity is not specified, a value of 0.3 m/s should be used as a guideline.

If minimum velocities are not likely to be maintained in a standard installation under normal operating conditions, designers must configure the installation, for example by using shrouds or rearranging flows, to maintain the minimum recommended velocity.

3.4.6 Cavitation

If NPSHA of the pump is less than NPSHR, the pumped fluid will vaporise in the region of the impellor eye, where the local pressure is less than the vapour pressure of water. In this region of the pump the fluid will consist of a mixture of water and vapour pockets. In severe cases a vapour lock can occur in the eye of the impellor.

Usually the vapour pockets progress through the impellor to a region of higher pressure. Here the pockets implode often with such rapidity that liquid impinges on the impellor vane with such force that material is removed from the impellor.

Cavitation may be caused by excessive suction lift, insufficient NPSHA or operation at too high a speed. The resulting effects include:

- Pitting of material surfaces due to the continual hammering of vapour cavities
- Reduction in performance due to vapour formation
- “Gravel” noise caused by vapour cavity collapse

To prevent cavitation designers must:

- Ensure that pumps operate within their recommended flow operating range
- Make sure that protection systems are in place to prevent pumps operating against closed valves for extended periods of time (check with pump manufacturers for recommended times – it may only be 5–10 seconds for some pumps)
- For pumps operating on variable frequency drives, frequency (hertz) does not fall below the minimum allowed by the manufacturers

Cavitation can occur with submersible pumps. In order to avoid cavitation, designers should:

- Ensure there is sufficient depth of water over the top of a pump when it is operating (need to allow for start-up conditions and normal operating conditions), taking into account water level variations
- Avoid high velocities past submersible motors, and
- Ensure motor shrouds are large enough and will not block

3.4.7 Power supply

Power available for the proposed irrigation system should be known prior to starting the design process. Size and proximity of the nearest transformer, other uses drawing on the transformer and cost of lines to reach the abstraction point are considerations to be discussed with the purchaser.

Once these considerations have been taken into account a case may be made for the use of alternative power sources, such as diesel fuel. If considering the use of diesel engines, designers should consult with engine suppliers and follow the manufacturer’s recommendations when specifying and sizing diesel engines.

3.4.8 Pump electrics

Electrical systems for pumps should include, at a minimum:

- A starter type that meets local lines company and energy supplier requirements
- A manual switch-on and switch-off for each pump
- High and low pressure or flow cut-outs
- High pressure or zero-flow cutoffs on the upstream side of pressure regulating valves, if fitted
- Low water level protection
- Fault indicators (to identify the reason for a fault)
- An external running light installed at the pump shed
- A circuit disconnect for each electricity connection
- Overload protection for every motor
- Phase failure and reversal protection
- Voltage and amperage display
- A running timer, and
- A total hour meter

Additional protection such as temperature sensors or control sensors should be installed where there is a risk of failure and the consequences of the failure are significant. For example, thermistor sensors or similar on submersible pump motors are highly recommended.

Electrical installers should take care to minimise electrical interference and noise resulting from the use of variable speed drives. Many electricity providers now require harmonic filters to be installed. Designers should check with relevant power supply authorities to determine local requirements.

3.4.9 Surface water intakes

In general, suction lines should be designed according to the following guidelines:

- All surface water intakes should have an appropriately sized screen or filtration system to exclude any debris present in the water source that may damage pumps or cause problems with the irrigation system. These 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
- All surface water intakes should exclude fish
- If the intake water level is below the pump, specify a check or non-return valve to prevent water from draining away from the pump when it is not in operation
- Ensure the suction pipe is of sufficient diameter and is installed at a sufficient depth below the lowest expected water level so that air is not drawn into the suction assembly
- Suction pipes should be as short as possible – refer to NPSH requirements
- Do not put any unnecessary valves or bends in the suction line
- Where valves are necessary, specify valves that are at least the same diameter as the suction pipe
- Where bends are necessary, specify long radius bends
- Ensure that the distance from any bends, valves, or pipe reducers to the inlet of the pump is at least five times the diameter of the pipe
- The suction pipe should be at least as large as the size of the pump inlet, and within five times the inlet pump diameter from the pump, equal to the pump inlet diameter
- Flexible couplings should be specified between pumps and rigid installations (suction or discharge) to prevent failure due to vibration
- Design the system so that shrouds, foot valves and filters or screens on the suction side can be easily kept clean
- Velocities through the suction pipe and intake screen should be less than those stated in *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012)

3.4.10 Headworks

Headworks should be designed to allow for easy control and monitoring of the system's operation. It should be readily accessible and easily maintained. All components of the headworks and their respective location within the headworks should be specified in the design.

The designer should consider the following:

- Specify galvanised steel for any above ground components of the headworks
- Understand and designs headworks systems to comply with national and local regional council water metering regulations
- Ensure that there is an accessible straight pipe for the measurement of flow rate using a portable meter. The length of this straight pipe should be at least 15 times its diameter. This is necessary, even in systems with an in-line flow meter because portable meters are often used to calibrate the in-line meter

There should be no other components within this length of pipe that would impede the flow of water and cause turbulence (e.g. butterfly valves, filters, or backflow preventers).

This pipe need not be part of the headworks. It could be any length of straight pipe (e.g. the mainline leaving the pump shed) so long as there are no water off-takes between it and the water source.

- Specify components with low friction losses (i.e. swept bends), wherever practical. This will help minimise the pump duty and operating cost of the final system
- The layout of the headworks should allow free access to all critical components (i.e. valves, meters, gauges). This is important for both normal operation of the irrigation system, and for maintenance
- Specify unions or flanges to allow the headworks to be dismantled non-destructively
- If multiple pumps are linked together, construct the manifold so that each pump can be independently isolated
- Include a facility to drain the headworks or irrigation system to ground
- If PVC is to be specified for use in the headworks (only recommended for small low pressure systems less than 2 kW):
  - Specify heavier walled material (e.g. PN12)
  - Specify increased support components to reduce load carrying requirement of PVC; and
  - Allow for malfunction (e.g. PVC getting hot and failing)

Consideration should be given to the order of components in the headworks. Awareness of the effect of turbulence on some components such as water meters, will determine headworks design. For example, having the check valve and control valve downstream from the water meter makes it easier to minimise unwanted turbulence above the flow meter.

If control valves need to be installed upstream of a flow meter, the straight pipe distance from the control valve to the flow meter should be increased. This will help to minimise turbulence through the meter.

If a control valve (e.g. a butterfly valve) is likely to be operated in a partially throttled state, which creates a high degree of downstream turbulence, the distance of straight pipe should be further increased, flow straighteners used or the valve should be moved downstream of the meter.

Ensure that any injection points (i.e. for effluent or fertiliser) are downstream of any backflow prevention devices and other sensitive instrumentation.

Protect sensitive components (e.g. backflow prevention devices) with a filter, as required by the component's manufacturer.

Flow measurement

A flow measuring device must be specified for all new spray irrigation systems and comply with relevant regulations... Refer to Section 4.6 of this document or to the *Guidelines for the Measurement and Reporting of Water Takes* (INZ, 2011) for more guidance regarding flow measurement and monitoring.

Pressure gauges

Pressure gauges or pressure sampling points are required on all irrigation systems. "Pressure gauges" refers to permanently installed gauges. "Pressure sampling points" refers to taps or fittings to which a portable gauge or meter may be attached.

The design should specify where pressure gauges or pressure sampling points are to be installed. Refer to Section 4.6 for a list of recommended locations.

It is considered good practice to specify pressure gauges (if used) with isolating stopcocks or similar so they can be turned off to prevent damage.

Control valves

Fit at least one control valve to every system to allow the water supply to be manually shut off from the rest of the system. The design should specify the type of valve to be used, and the location in which it should be installed.

It is recommended that the main control valve be of a slow-opening/closing variety (i.e. not a butterfly valve). Quick opening/closing valves have the potential to cause water hammer and put pipelines and pumping equipment at risk of significant damage.

Do not use valves that can only be fully open or fully closed in situations where the system can be started with empty mainlines.

Always use valves of a diameter at least as large as the pipe in which they are being installed.

Air release/vacuum breaker

Specify an air release valve/vacuum breaker at the highest point in the headworks.

Chemical injection

Allow for the possible connection of chemical injection into the system, by including the appropriate fittings in the headworks design. The size of the bungs will be determined according to expected injection flow rates.

Injection points should always be placed downstream of a backflow preventer. See the *Backflow Prevention Guidelines* (INZ, 2012) for further requirements.

Check with local regulations to determine if there are any further requirements for fertiliser injection.

Protection from freezing

Designers must add protection to systems subject to freezing. The risk of damage to components from freezing must be determined and measures taken to prevent damage.

Although the number of irrigation systems likely to be operated during freezing conditions is likely to be limited, systems can freeze if not designed and managed correctly.

Backflow 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. Refer to the *Backflow Prevention Guidelines* (INZ, 2012) for further guidance.

3.4.11 Pump sheds

All pumping systems should be supplied with a shelter to house equipment that is sensitive to weather (i.e. motors, control systems, and gauges). Although some pumps can be outside under a simple roof or rain shelter, all electrical equipment must be located in a lockable shed.

When specifying a pump shed, ensure that it:

- Is adequately sized to house all equipment, and allows sufficient working room
- Protects equipment from the elements, especially rain
- Protects equipment from animals, including nesting birds
- Protects equipment from flooding (i.e. sheds)
    - Are not located in areas prone to flooding, and
    - Have adequately sized drains installed in the floor
- Has proper ventilation and cooling
- Has at least one 230V outlet
- Has light fixtures to illuminate the controls for the system operator
- Complies with the New Zealand Electrical (Safety) Regulations requirements

3.5 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
- Computer-based systems

There are a number of options designed around these main methods, and each designer and/or system supplier is likely to have their own range of options. Control systems must be matched to the needs of the purchaser and work properly.

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 and communication systems
- 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 grazing, mowing, spraying, picking crops
- Labour savings (no need to go into the field to turn valves on and off)
- Providing information feedback (what has happened in field) and record keeping

Some precautions that should be considered at the design stage include the following:

- Where an irrigation system has problems with unwanted shutdowns, the problems with the irrigation system must be sorted out first – before adding more components
- Safety shutdown controls should always override restart controls, so that full protection is maintained
- Restart attempts should be limited if other problems are likely
- Elevation differences between pumps and irrigators should be taken into account
- Systems pumping uphill should remain full.
- Pipelines running downhill should have appropriate measures to control emptying of pipelines (e.g. vacuum breakers)
- Careful analysis and testing should be carried out on systems with very high pressures, complex combinations of pumps, or very long pipelines
- Allow for expansion or changes in design. Many of the new control systems are modular, which means that as many modules as required can be added to cover expansion
- If the central controller is installed outdoors, it should be housed in a waterproof cabinet. Be aware that connecting a 240V power supply to an outdoor installation may add significant additional expense
- Supply information about what to do if a system malfunctions

In systems with varying or multiple demand points (such as horticultural blocks), the control system should be able to operate pumps at their maximum efficiency points and at uniform flow rates.

Effluent

For guidance on automatic control and alarm requirements in farm dairy effluent systems refer to the *Farm Dairy Effluent* (FDE) *Design Code of Practice and Standards* (DairyNZ, 2010)

3.6 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 measurement and monitoring equipment should be planned for and included at the design stage of the process.

Flow measuring devices

A flow measuring device that records flow rate and total volume should be specified for all new irrigation systems. Refer to *Guidelines for the Measurement and Reporting of Water Takes* (INZ, 2011), which provides a detailed description of requirements for flow measuring devices.

The measurement and recording of flow provides the basis for determining overall system performance. For a number of regional councils, it is also a required condition of the water take resource consent. From the purchasers' perspective, flow records provide the opportunity to verify system performance (i.e. actual volume of water applied versus design values). Flow 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 best determined using flow measurement. For piped irrigation systems, this is usually done with a water meter.

Automatic logging of measurements is becoming commonplace, and generally provides more accurate and complete information than manual recording of flow data. The meter or gauge records can be readily transferred to standard spread sheet 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) provide the basis for the assessment of water demand and water balances.

Water meter selection should be based on the following:

- The accuracy of the meter should comply with *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012) and the conditions of the resource consent
- For in-line meters, the nominal diameter of the meter should not be less than the pipe diameter upstream and downstream of the meter
- Designers should allow for straight sections of pipe upstream (ten times nominal diameter) and downstream (five times nominal diameter), unless more stringent requirements are specified by the meter manufacturer or stipulated by resource consent conditions
- Even if an in-line flow meter is not specified, it is still recommended to install an accessible straight piece of pipe whose length is at least 15 times its diameter. This will allow for the use of a portable flow meter, or for the installation of an in-line flow meter, at a later date

Pressure gauges

Pressure gauges or pressure sampling points are required on all irrigation systems. "Pressure gauges" refers to permanently installed gauges. "Pressure sampling points" refers to taps or fittings to which a portable gauge or meter may be attached.

The design should specify where pressure gauges or pressure sampling points are to be installed. At a minimum, specify pressure sampling points or preferably gauges at the following locations:

- Anywhere in the system where pressure monitoring is being used (e.g. at pressure transducers and pressure switches)
- The inlet of all surface pumps
- The outlet of all pumps, upstream of any in-line components
- Upstream and downstream of components with a large head loss (i.e. backflow preventers)
- The outlet of headworks, downstream of all in-line components
- The inlet to each irrigator or irrigation block, downstream of all hydrants, connecting hoses and control valves
- A second gauge should be specified near the last outlet of an irrigator if a large head loss is expected through the machine or hose (e.g. at the end of centre-pivots, or at the gun-cart of a hard hose gun system)

Some in-line components (i.e. valves or reducers) are likely to cause turbulence in the pipe that may interfere with pressure gauge readings. Ensure gauges or pressure sampling points are at least two pipe diameters upstream and at least three pipe diameters downstream from these components. This will provide for more accurate pressure readings.

It is good practice to specify pressure gauges (if used) with a stopcock (or similar) so they can be isolated from system when not in use to prevent damage from water hammer or high pressure surges. This will extend the working life of the gauges and will allow for them to be checked or replaced while the system is running.

Water levels

A method for monitoring water levels in water sources (lakes, ponds, production wells and any associated monitoring wells, if required for compliance) should be specified in the design. A range of methods are available, and the designer should recommend the option that is best suited to the needs of the purchaser.

If not required for operational purposes, water levels may be measured manually through an access tube into a well (dip probe or suction gauge). Automatic monitoring of water levels (i.e. with a float recorder/datalogger or pressure transducer/datalogger) is recommended for all systems using water levels within control systems to manage or automate system operation.

The designer should discuss preferred water level monitoring options with the purchaser. The water take resource consent may require a particular method of monitoring.

Water quality

The designer must ensure access points are included for water samples to be taken from the system for water quality monitoring. A sampling tap at the headworks is recommended for all systems for this purpose.

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.

Designers should discuss soil moisture monitoring options with the purchaser, including automatic control options based on soil moisture monitors.

Power consumption

It is useful to have some way of monitoring operational power consumption. It is good practice to display volts and amps somewhere in the pump shed for this purpose.

Some systems also include a display showing kW (this is standard on most variable speed drives), which is particularly useful for monitoring energy consumption Performance Indicators.

Effluent Dispersal Systems

For guidance relating to the measurement and monitoring of farm dairy effluent systems refer to *Farm Dairy Effluent* (FDE) *Design Code of Practice and Standards* (DairyNZ, 2012).

3.7 OTHER ACCESSORY COMPONENTS

Air release

Specify one air release valve for highest point in the headworks.

For irrigation systems with longer pipelines, it is recommended to include at least one additional air relief valve for every 1,000m of pipe.

For irrigation systems located in undulating terrain, it is recommended to include air release valves at all high points where air may build up.

When sizing and specifying air release valves designers should follow manufacturer's recommendations.

Pressure or vacuum relief

A pressure relief valve is recommended for situations where the pressure rating of the system (e.g. the pressure rating of the pipe) may be occasionally exceeded.

A vacuum relief valve is recommended for situations where a negative pressure may be experienced.

The design should specify if pressure or vacuum relief valves are necessary. It should also specify the type of valve to be used, and the location in which it should be installed.

When considering type and size of pressure or vacuum relief valves designers should follow manufacturer's recommendations.

3.8 CHECKING PERFORMANCE TARGETS

Prior to finalising the design, check that it matches the performance parameters that were set prior to starting the design process (see Section 3).

Complete the necessary calculations to compile a list of the Performance Indicators for the system. Table 2 provides a list of the recommended Performance Indicators, and Appendix B provides most of the standard formulae necessary to calculate them.

The Performance Indicators calculated for the design should be reviewed with the purchaser, and these should be compatible with:

- The performance parameters set out at the beginning of the design process
- The requirements of *The New Zealand Piped Irrigation Systems Design Standards* (INZ, 2012)
- All relevant resource consent conditions
- Any other relevant local or central government regulations

4 Final specification and quotation

4.1 FINAL SPECIFICATION REPORT

A specification report and plan summarising the final system performance indicators must be provided to the purchaser. This document will describe the final system composition and what it will be capable of achieving. It will be completed in sufficient detail so that quotations for the supply and installation of the system may be obtained.

Depending on the particular situation, the design report may be submitted in conjunction with a quotation for supply.

A quotation based on the system specification must be supplied to the purchaser, so that all parties are clear about what is going to be provided. The following information should be clearly visible within any quotation:

Designer information

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

Purchaser information

- Name of purchaser
- Contact details of purchaser (e.g. address, phone, fax, and email)
- Name of property
- Location of property

Input Information and Assumptions

Includes all input values determined during the initial site investigation:

- Site layout
- Water source
- Soils information
- Crop types
- Climate assumptions (e.g. evapotranspiration and rainfall)
- Regulatory requirements
- Farm management needs

System specification

The system specification should describe the irrigation system in enough detail so that a quotation may be obtained. It should include a physical description of the system and a description of the expected system performance, including the following:

- Irrigation method
- Effective irrigated area
- System capacity
- Pumping rate
- Pump operating pressure
- Depths of application
- Maximum return intervals
- Application intensity
- Design application uniformity or appropriate measure of uniformity
- A list of the other expected Performance Indicator values
- Pump size and a description of build quality
- Pump motor type and speed
- Pipe lengths and pressure ratings
- Pipe fittings and other accessory components
- Water supply requirements (e.g. new well or surface water intake)
- System monitoring requirements
- Power supply requirements
- Pump shed requirements
- Plan, showing the locations of the proposed infrastructure and the land application area(s)

Expected operating costs

Operating costs are often an overlooked component of irrigation system design and quoting. Designers must quantify or estimate the following expected operating costs, according to the Performance Indicators described in Table 1:

- Labour to operate irrigation system
- Energy costs of running the system
- Maintenance costs

Operating cost should be expressed as cost per unit area ($/ha) and cost per unit volume of water ($/m^3).

Technical analysis

The designer should provide sufficient information to the purchaser to show that the technical 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.

5 Implementation

While the primary role of the designer is to complete the design calculations and create a system specification, some of the designer's responsibilities often spill over into the implementation phase. *The New Zealand Piped Irrigation Systems Installation Code of Practice* (INZ, 2012) provides a detailed description of the installation and commissioning process, including an explanation of the designer's role throughout. A summary of the designer's responsibilities in the implementation phase is provided here.

General

The irrigation system designer must provide all necessary information to the installer. This will include drawings, plans, or specifications that the installer requires to correctly install the system. This responsibility may extend beyond the initial design specification (i.e. where unforeseen problems arise during the installation process).

The installer is often contracted to, or employed by the designer. In this case, the designer must:

- Ensure that the installer has the necessary relevant skills prior to starting work
- Monitor the progress of the installation to ensure that the design specifications are being met
- Oversee the commissioning of the system

If the installer is contracted directly to the purchaser, the purchaser takes on these responsibilities. However, the designer is still often asked to help with these roles.

It is in the best interest of all parties to ensure that an appropriate contract is prepared to outline these roles prior to beginning the implementation process.

Installation

The installation of spray irrigation systems involves close cooperation between the purchaser, designer, and the installer(s). In many instances, the installer and designer may be the same entity, although this is not always the case.

The system must be installed in accordance with the design specifications prepared by the designer, and agreed by the purchaser. Where something is not explicitly specified by the design, the installer may need to consult the designer for further clarification.

The system designer and the purchaser must both accept any variations to the original specification.

Commissioning

A properly executed commissioning process will demonstrate whether or not all components of the system are installed and operating properly, and in accordance with the system specification, over the range of on-site conditions expected.

The designer is often involved in this process, either at the system testing phase, or to provide input on how to correct performance issues.

Manuals and training

When an irrigation system is handed over to the purchaser, it should be accompanied by:

- A commissioning report
- As-built plans
- Operation and maintenance manuals, and
- Any other relevant support information

The New Zealand Piped Irrigation Systems Installation Code of Practice (INZ, 2012) stipulates that the installer is responsible for supplying this documentation to the purchaser. However, the designer may be asked to provide much of the information that goes into these documents.

Training must be made available for the purchaser and system operator that covers all of the main items in the operation and maintenance manuals. The designer may be asked to participate in administering this training.

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Definitions

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

Adequacy of irrigation: A measure of the proportion of the target area for which the soil is restored to a target soil water content. This is calculated as the ratio of the mean low quarter depth applied, to the mean required (target) depth.

Application depth: The rainfall equivalent depth of water applied to the soil surface during a single irrigation event. It is the depth of water that would be caught in a rain gauge, not the depth of soil that is wetted.

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

Application intensity: The rate (mm/hour) at which irrigation is applied. It compares "gentle showers" with "heavy rain". (See specific calculations below).

- **Instantaneous Application Intensity (R_i)**
  The rate (mm/hr) at which irrigation is applied by an individual stream, from an individual outlet or nozzle, to a very small area. For example, for a rotating boom it is the flow from a single outlet divided by the area being wetted at any instant by that outlet.
- **Average Application Intensity (R_a)**
  The rate of application (mm/hr), averaged over the individual applicator's wetted footprint. For example, for a rotating boom it is the applicator's flow rate divided by the area wetted by one full rotation of the boom.

Application uniformity: The spatial variability of application. This can be defined in a variety of ways. Common examples are:

- Distribution Uniformity (DU)
- Coefficient of Uniformity (CU)
- Coefficient of Variation (CV)

Back flow preventer: Device designed to prevent water from flowing in reverse through the system. Commonly used to prevent added nutrients, chemicals or effluent from mixing with clean water sources.

Capital cost: The overall system purchase and installation cost ($). Expressed as a cost per unit area ($/ha) as a total or annualised cost.

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

Distribution efficiency: A measure of how much of the water supplied to the property reaches the application system. It is a function of losses 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 volume of water that percolates beyond the root zone, based on peak irrigation demand. This is typically expressed as a volume per unit area (m^3/ha) or an equivalent depth per unit area (mm/ha).

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

Evapotranspiration (ET): The rate of water loss from a combined surface of vegetation and soil. It includes evaporation of water from the soil and plant surface and transpiration by plants.

Field capacity (FC): The soil moisture content after gravitational drainage slows from a saturated condition to a rate that is insignificant (i.e. drainage rate less than 1 mm/day).

This is usually estimated in the field by measuring the soil water content 2–3 days after heavy rainfall, or by measuring the water content of soil cores in the laboratory after they have been equilibrated at a soil matric potential.

In New Zealand the laboratory estimation of field capacity is measured at the nominal -10 kPa soil matric potential, but direct field measurements show that it can vary between -2 kPa to -30 kPa depending on soil texture.

Headworks efficiency: A measure of the hydraulic performance of the intake structure, pump and headworks (excluding pump pressure and elevation differences) to indicate the extent of pressure loss in the water supply system between the water supply point and the mainline entry.

Hydraulic efficiency: A measure of the system hydraulic performance; it gives an indication of how much pressure is lost between the delivery (mainline entry) and discharge points (machine entry, hydrant, or take-off in drip-micro systems), excluding variations in elevation.

Infiltration rate: The movement of water into the soil profile. Measured as the rate (mm/hour, mm/day) at which a soil absorbs water. It varies with soil type, soil surface condition and moisture content.

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

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 allowed depletion (MAD): The proportion of the Crop Available Water that is allowed to be removed before irrigation is applied. The level is a management decision dependent on crop type, stage of crop development, seasonal water demand and other management factors and constraints.

Note: this term is not to be confused with *maximum allowable deficit* which is another term for the trigger point.

Permanent wilting point (WP): The soil moisture content where plant growth stops.

This is the lower limit of available water below which plant growth ceases completely. The soil matric potential at this point corresponds to about -1,500 kPa (-15 bar). The 'permanent wilting point' is generally governed by the amount of clay in the soil – the greater the amount of clay, the higher (% soil moisture) the 'permanent wilting point'.

Operating costs: The costs directly attributable to the operation of the irrigation system.

- Labour to operate irrigation system
- Energy costs of running the system
- Maintenance costs

Operating cost should be expressed as cost per unit area ($/ha) and cost per unit volume of water ($/$m^3$).

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 (depth) (RAWD): The rainfall equivalent depth of 'readily available water' by a specified crop from its root zone.

The root zone depth in centimetres is shown as a subscript following the acronym (e.g. RAW40 is the 'readily available water' in the 40 cm deep root zone in a given soil).

Return interval (Return period): The typical period between one irrigation event and the next. It is usually calculated for the most demanding period so that the irrigation system can meet water demand most of the time.

Return on water use: The marginal change in returns resulting from the irrigation system. It is generally based on mean annual irrigation demand, and incorporates cost and productivity elements above. Values can be expressed as returns per unit area or volume of water ($/ha or $/$m^3$). Values can be positive or negative, dependent on system costs, productivity and crop returns.

Scheduling co-efficient: Used to determine how much extra irrigation should be applied to ensure that most of the crop gets sufficient water. It accounts for variances and inefficiencies of application systems.

It is common to use the reciprocal of the low quartile Distribution Uniformity to calculate the extra required. Multiplying irrigation need by the scheduling coefficient determines a target application depth that ensures that 7/8th of the crop will receive at least the required depth of irrigation (some will get considerably more).

Surface runoff: Water that does not immediately infiltrate into the soil and instead leaves the target zone by running off across the soil surface under gravity.

System capacity: The flow of water per unit of irrigated area normally expressed as litres per second per hectare (L/s/ha) or mm per day (mm/d) calculated on the basis of the system operating 24 hours per day.

Total available water (TAW): All the water that is extractable by plants (plant type may be specified); taken as the difference between soil water at field capacity and at permanent wilting point.

Water holding capacity (WHC): The volumetric ratio of all water contained in a layer or depth of soil at field capacity, including that held too tightly for plants to access.

Appendix A: Abbreviations and symbols

The following abbreviations and symbols are used throughout this document and in the design equations in Appendix B:

A	Area of the irrigated strip (m^2)
AE	Application efficiency
CU_c	Christiansen coefficient of uniformity
Cv	Coefficient of variation
Cv_{man}	Coefficient of variation due to manufacturing
D_{app}	Applied depth
Dc	Critical deficit
DU	Distribution uniformity
DU_{lq}	Low quarter distribution uniformity
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

Base calculations

Eqn 1 Coefficient of variation (C_v)

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

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

Where:

C_v	is the coefficient of variation
s	is the standard deviation in the sample
$\bar{x}$	is the mean value from the sample

Eqn 2 Standard deviation from the mean (s)

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

Where:

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

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

Eqn 3 Emitter pressure flow relationship

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

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

Where:

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

Eqn 4 Emitter discharge exponent

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

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

Where:

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

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

Eqn 5 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.

Application calculations

Eqn 6 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	is irrigation requirement
ET_{crop}	is crop water use by evapo-transpiration
WR_b	is beneficial water requirement applied by irrigation system
P	is precipitation
ASM	is available soil moisture
DU_{lq}	is low quarter distribution uniformity

Eqn 7 Total system application depth (D_{mf})

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

Where:

D_{mf}	is the mean application depth based on system flow rate (mm)
Q_m	is the system flow rate (m^3/h)
T_{irrig}	is the duration of an irrigation event (hours)
A	is the area of the irrigated strip (m^2)

Eqn 8 Infiltration depth (drip-micro and long-lateral)

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

Where:

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

Eqn 8 Equivalent applied depth (drip-micro)

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

Where:

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

Eqn 9 Instantaneous application rate (R_{it})

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

Where:

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

Eqn 10 Instantaneous application rates – linear move (R_{il})

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

Where:

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

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).

Eqn 11 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}	is the instantaneous application rate at radius, r (mm/hr)
r	is radial distance from pivot centre to point under study (m)
W	is the wetted width (diameter) of nozzle pattern at r (m)
Q_f	is the discharge for the full irrigated circle (L/s)
r_e	is the effective radius of the full irrigated circle (m)

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

Uniformity calculations

Eqn 12 Distribution uniformity (DU_{lq})

This Code adopts the low quarter distribution uniformity ratio. The low quarter distribution uniformity coefficient formula is:

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

Where:

DU_{lq}	is the lowest quarter distribution uniformity coefficient
V_{lq}	is the average volume (or alternatively the mass or depth) of water collected in the lowest quarter of the field
$\overline{V}$	is the average volume (or alternatively mass or depth) of water collected by all collectors used in the data analysis

Eqn 13 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	is the Christiansen coefficient of uniformity
n	is the number of collectors used in the data analysis
i	is a number assigned to identify a particular collector
V_i	is the volume (or alternatively the mass or depth) of water collected in the ith container
$\overline{V}$	is the arithmetic average volume (or alternatively mass or depth) of water collected by all collectors used in the data analysis, calculated as:

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

Eqn 14 Emission uniformity (EU)

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

$$EU = (1.0 - C_v)$$

Where:

EU	is the statistical emission uniformity
C_v	is the coefficient of variation

Eqn 15 Emission vs Distribution Uniformity
Emission uniformity (EU) is related to low quarter distribution uniformity (DU_{lq}) by the equation:

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

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

Eqn 16 Emitter emission uniformity (EEU_{lq})

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

Where:

EEU_{lq}	is the emitter emission uniformity
Cv_{man}	is the coefficient of emitter manufacturing variation
Cv_{defect}	is the mean coefficient of variation due to blockages, wear and tear determined from emitter tests 1, 3 & 4.
n	is the number of emitters per plant

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

Eqn 17 Design Uniformity (EU_{des})

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

Where:

EU_{des}	is design emission uniformity
Cv_{man}	is the manufacturer's coefficient of variation of emitters
n	is the number of emitters per plant
q_m	is the mean low quarter emitter discharge due to the mean low quarter pressure
q_a	is the overall mean emitter discharge

(Keller and Karmeli, 1974: ASAE 405.1)

Efficiency calculations

Eqn 18 Application Efficiency

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

Eqn 19 Potential soil moisture deficit (PSMD)
A measure of moisture stress experienced by a crop, calculated using:

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

Where:

$PSMD$	is potential soil moisture deficit in any period where SMD>Dc
SMD	is the soil moisture deficit
D_c	is the critical deficit

Eqn 20 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):

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

Where:

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

Eqn 21 Seasonal deep percolation (SDP)
Includes all drainage, whether from irrigation or precipitation. It is estimated from the balance of water not retained in the root zone, calculated after any surface losses have been accounted for.

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

Where:

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

Eqn 22 Seasonal irrigation deep percolation (SDP_i)
Seasonal deep percolation resulting from irrigation is a measure of the amount of irrigation water applied that drains from the soil profile. It is, in effect, seasonal application in-efficiency.

$$SDP_i = (1 - SAE)$$

Where:

SDP_i	is seasonal deep percolation from irrigation
SAE	is seasonal application efficiency

Eqn 23 Drought induced yield loss (YL_{di})
Calculated from potential (client expected) yield, PSMD and the drought response factor:

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

Where:

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

Eqn 24 Value of lost yield (YL_v)
The value of lost yield is determined from the value of the crop and the amount of lost yield.

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

Where:

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

Miscellaneous equations

Eqn 25 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	is the well drawdown
K_d	is the discharge coefficient
Q	is the flow rate
x	is the well exponent

Eqn 26 Hazen Williams formula

$$H = \frac{1.213.10^{10} \times Q^{1,852} \times L}{C^{1,852} \times {D_h}^{4.871}}$$

Where:

Q	is the flow (ℓ/s)
L	is the length of pipe (m)
C	is the Hazen Williams roughness
D	is the 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.

Appendix C: Design table templates

Table 4 provides a list of the topics that should be discussed during the property visit, and provides space to record notes. Table 5 is an example of how key performance indicators can be included in a design report.

Table 4 Property visit checklist

Item	Notes
Site Layout	
Map	
Topography	
Design area	
Fencing	
Shelter	
Land restrictions	
Energy source	
Vandalism	
Water Supply	
Water supply location	
Water quantity	
Water supply reliability	
Water quality/chemistry	
Soils Information	
Soil type	
Available water holding capacity	
Effective crop rooting depth	
Management allowable deficit (MAD)	
Infiltration rate	
Drainage	
Variability	

Item	Notes
Climate Information	
Rainfall	
Evapotranspiration	
Wind	
Regulatory Requirements	
Resource consents	
Farm Management Information	
Animals	
Crops	
Other water needs	
Labour	
Future flexibility	
Risk preference	
System type	
Process Control	
Price limits	
Delivery	
Health & Safety	
Other	

Table 5 Design specification

Table 6 Please check.

Performance Indicator	Unit(s)	Indicator Value
System capacity: (based on 24 hours)	l/s/ha mm/day	
Ratio of system capacity to peak season crop irrigation demand	%	
Application depth	mm (range)	
Ratio of applied depth to the design maximum management allowable deficit (MAD)	%	
Return interval	days hours	
Ratio of application intensity to soil infiltration rate	%	
Application uniformity	% ratio	
Adequacy of irrigation	ratio	
Potential application efficiency	%	
Distribution efficiency	%	
Mainline efficiency	%	
Headwork efficiency	%	
Energy Use Efficiency		
System pumping efficiency	%	
Pump Operating Cost	$/ha/yr $/m^3	

NOTES

NOTES

REFERENCES

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