Best Management Guidelines for Sustainable Irrigated Agriculture

MAF Policy Technical Paper No 00/05

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Disclaimer

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Foreword

This is one of a series of 10 technical bulletins, which report the detail of projects commissioned by MAF Policy on sustainable irrigation.

This work arises as part of MAF's contribution towards Government's "Sustainable Land Management Strategy."

The projects in this series broadly divide into two groups, technical irrigation design factors and management factors. A key issue identified by farmers at the onset of this work was that to ensure irrigation could operate in sustainable ways physically and for the environment, it also had to be profitable irrigation.

The emphasis on water use efficiency and cost effectiveness of plant and management, which has arisen from this, has been developed throughout the research. It is clear that win/win situations are possible. Improvements for both environmental and farm profitability objectives can be achieved.

More efficient ways of monitoring and managing water use on farms are described in the series.

There is a large amount of base data and technical information in these papers which is likely to be helpful background for designers, consultants and local and regional authorities.

Much of this information is also being incorporated into a simpler National Irrigation Handbook. This is being designed as a ready reference for farmers and commercial firms, and will be available in 2001.

An overall summary of the technical reports in this series and copies of the reports themselves can be obtained from: Information Bureau, Ministry of Agriculture & Forestry,
PO Box 2526, Wellington.

A B Walker
Director
Policy Information & Regions

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Summary

The principal objective of this project is:

To develop best management guidelines which provide practical information and advice that farmers can use to make, document and revise decisions relating to the design and operation of irrigation systems, to achieve sustainable irrigation.

The best management guidelines are to help farmers obtain the benefits of well-designed and operated irrigation systems. These benefits are:

Increased crop production:
- improved environmental performance including reduced contamination of groundwater and reduced impacts on aquatic habitat values in rivers and streams;
- efficient use of resources - water, energy and labour; and
- reduced risk of crop and business failure.

In a previous study funded by MAF Policy (LE Report No 2720/1†), sustainability goals for the environmental, social and economic aspects of farming were defined. A set of indicators that farmers could use to measure and report on the sustainability of their irrigation management practices was presented.

The best management guidelines provide practical advice on how to use and apply the indicators defined in the previous report, to achieve sustainable irrigation through better design and management of irrigation systems. The guidelines will be field-tested in the 1997/98 irrigation season.

The overall goal of irrigation is usually to maximise net profit over the long term, although the environmental and social goals of irrigation are also very important. To achieve this goal, farmers need to make daily, seasonal and long-term decisions with respect to the design and operation of their irrigation systems within the following areas:

- new system design;
- preseason checks;
- planning the irrigation strategy for the season;
- operating and managing the irrigation system during the season; and
- reviewing the performance at the end of the season.

The best management guidelines provide information to help farmers make better decisions within these areas. The guidelines also specify a process that farmers can use to evaluate the effectiveness of their decisions to continually improve the sustainability of irrigation practices, and to demonstrate the sustainability of these practices to regulatory authorities.

† Lincoln Environmental Report No 2720/1, June 1997, *Indicators of Sustainable Irrigated Agriculture.*

1 Introduction

1.1 PURPOSE OF PROJECT

MAF Policy has identified operational research objectives relating to facilitating resource management to:

"Promote sustainable farm and orchard management planning including the collaborative development of best management practice guidelines."

and has funded a series of projects aimed at meeting these objectives.

The principal objective of this project, which is the second in a series of projects related to irrigation is:

To develop best management guidelines which provide practical information and advice that farmers can use to make, document and revise decisions relating to the design and operation of irrigation systems.

The best management guidelines are to help farmers obtain the benefits of well-designed and operated irrigation systems. These benefits are:

- increased crop production;
- improved environmental performance including reduced contamination of groundwater and reduced impacts on aquatic habitat values in rivers and streams;
- efficient use of resources - water, energy and labour; and
- reduced risk of crop and business failure.

The first project within the operational research objectives funded by MAF Policy (LE Report No 2720/1†) defines sustainability goals for the environmental, social and economic aspects of farming. The report presents a set of indicators that farmers can use to measure and report on the sustainability of their irrigation management practices.

Following the Indicators Report, this, the second project, provides practical guidelines on how to use and apply the indicators to the design and management of irrigation systems. Further projects will assess farmers' perceptions of current practices, opportunities and restrictions relating to irrigation. The indicators and best management guidelines will be field-tested in the 1997/98 irrigation season.

† Lincoln Environmental Report No 2720/1, June 1997, *Indicators of Sustainable Irrigated Agriculture.*

1.2 APPROACH

The design and operation of irrigation systems requires farmers to make daily, seasonal and long-term decisions within the following main areas:

- new system design;
- preseason checks and planning;
- operation of the system; and
- review of performance.

There are a number of steps in the process. For new designs they are:

- an assessment of whether to irrigate or not;
- finding a water supply;
- determining system capacity, application depths and rates;
- the type of system to use;
- design/purchase/installation; and
- testing and commissioning.

After installation of new systems, and for existing systems, further steps are:

- pre-season checks;
- operating and managing the irrigation system during the season;
- reviewing the performance at the end of the season; and
- maintaining the system.

The decision-making process should lead to the overall goal of irrigation, which usually is to maximise net profit over the long term. The environmental and social goals of irrigation are also very important, but unless the basic economic goal of making a profit is met, irrigation will not be sustainable in the long term.

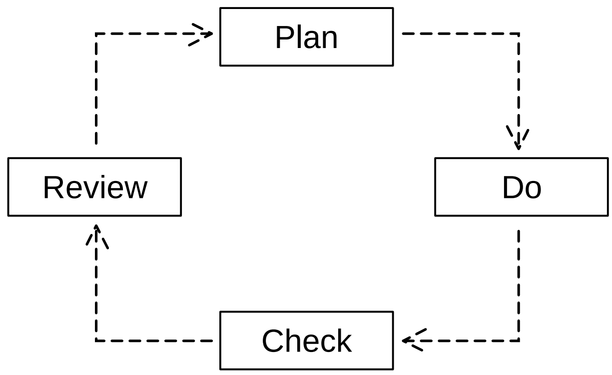
The correct selection of the system to ensure that it will meet farmers' needs is vital to the success of irrigation. The design of the system sets the platform for all future operations. How the system is then operated and managed during the season determines the overall success of irrigation.

Daily decisions, such as where to irrigate and how much water to apply must be made. Irrigation strategies, crop choices, and crop priorities for allocating water have to be determined, and the irrigation system must be maintained. In the longer-term, decisions such as applying for changes to or reapplying for resource consents and replacement or upgrading of irrigation equipment must also be made.

Irrigation can be most effective if clear objectives with measurable performance criteria are specified. "What are you trying to achieve and how will you know if you are going in the right direction?"

The Indicators Report provides a formalised set of goals, which defines the objectives of irrigation and addresses the environmental concerns, and economic and social interests of farmers. The indicators recommended in the report are performance measures for these objectives, which can be used to help farmers make informed and defensible irrigation management decisions. Feedback from the indicators can be used to continually improve the sustainability of farming practices and to demonstrate the sustainability of farming practices to regulatory authorities.

A good decision-making process involves a feedback loop such as:



The plan-do-monitor-review process described above is a structured way of continually improving a process and is recommended in both quality assurance and environmental management systems. It creates a cycle by which the consequences of decisions made and implemented can be checked and future decisions altered accordingly.

Farmers can apply this type of decision-making framework to the daily, seasonal and long-term decisions required for irrigation.

In general, farmers should take the seasonal indicators listed in the Indicators Report and set targets or directions for improvement. In the first few years of operating under these guidelines, it will be difficult to set targets and to determine whether an indicator value, such as the production per unit of water, represents good management. With continual use, however, farmers and others will gain a better understanding of how their actions influence the indicator values and it will be easier to set targets and goals. MAF Policy is funding a project in the 1997/98 year to trial these guidelines. These guidelines will provide the means to obtain values for the indicators for the trial farms, and should provide farmers with a starting point for setting their own targets.

1.3 RECOMMENDED INDICATORS

The indicators recommended in LE Report No 2720/1 are summarised below:

Economic	
1.	Annual net operating profit after tax ($)
2.	Quantity of crop or product produced per unit of water used for each crop (t/m^3)
3.	Profit per unit of water used ($\$/m^3$)
4.	Quantity produced/hectare for each crop or product (t/ha)
5.	Quality of produce (% of each crop or product at each grading level)
6.	Annual energy used to operate irrigation system (kWh)
7.	Energy used per volume of water pumped (kWh/m^3)
8.	Labour units per irrigated area (hours/hectare)
Environmental	
3.	Resource consents obtained and complied with
4.	Indicator of soil health
5.	Evaluated from soil water holding capacity, total organic Nitrogen and Carbon, pH and conditions of soil surface aggregates
6.	Daily volumes of irrigation water flowing onto farm for each crop (m^3)
7.	Daily percentage of water flowing onto the farm that is stored in the root zone (derived from soil moisture measurements in and below the root zone)
8.	Daily visual assessment of the amount of ponding or surface water runoff
9.	Maximum water abstraction rate each season (m^3/day)
10.	Lysimeter-based measurement of nitrogen leaching below the root zone (effluent irrigation only)
11.	Agrichemicals and fertilisers used per quantity of crop produced (kg/ha or *l*/ha)
Social	
1.	Record of any abatement notices

The following information is required:

Daily	Seasonally Or Annually	Long-Term
• Water volumes onto farm • Soil moisture in and below root zone • Visual assessment of ponding or surface runoff • Rainfall	• Net profit • Production quantities • Quality of produce • Energy use • Labour spent on irrigation • Soil pH • Total organic N and C • Soil surface aggregates • Fertiliser and agrichemical use • Area of each crop • Lysimeter-based measurement of leached nitrogen (effluent irrigation only)	• Resource Consents • Abatement notices • Soil water holding capacity • Areas of each soil type

2 Basic Principles of Irrigation

2.1 THE SOIL-WATER BALANCE

Irrigation systems are used to manage the amount of water stored in the soil.

Evapotranspiration (ET) or consumptive use, which is the combination of water evaporated from the soil surface and the water transpired by plants, causes soil moisture to decrease over time. If rainfall or irrigation does not replace this water, soil moisture falls to the extent that plants reduce growth and ultimately wilt and die.

In the absence of rainfall, irrigation is used to maintain soil moisture at a level that plant growth generally is not limited.

When irrigation is applied, the rate at which water moves through the soil depends on the soil type. In clay soils, this rate is quite slow, while in sandy soils, the rate is usually quite rapid. After irrigation or significant rainfall, the upper layers of the soil may become saturated, depending on the depth applied. Water applied in excess of what the soil can retain will drain into the deeper layers, usually the groundwater system. The excess water drains out under the force of gravity, and after a few hours in light free draining soils, or perhaps several days in tighter soils, the soil is said to be at **field capacity** or at the **full point**. Plant growth generally does not take place in saturated soils, so excess watering may have a detrimental effect on plant growth.

As the soil dries out, the rate of evaporation from the surface falls fairly quickly until the soil surface is dry. The remaining soil moisture, which is usually the majority of the available water, is used by plants for transpiration and growth.

The rate at which plants absorb water reduces as the soil dries out, because it becomes progressively harder for the plants to suck the water from the soil. Initially plants are easily able to draw water from the soil, and growth is not affected. After some time the soil becomes dry enough to slow plant growth. This soil moisture level at this stage is known as the **critical deficit**, or the **stress point**. The rate at which the atmosphere can suck water from the plants exceeds the rate at which plants can absorb moisture, and temporary wilting may occur. This soil moisture level is often considered to occur at a soil suction (soil tension) of about 1 bar, although this varies with different crop types, and is the point at which irrigation should be applied to return plants to full growth.

If the crop is not irrigated or water is not received from other sources, the soil will eventually dry out to the point where permanent wilting occurs, and the plants will die.

The amount of water in the soil between the stress point and field capacity is called the **readily available soil moisture**. Theoretically, the most efficient irrigation is achieved when soils reach the stress point and enough water is applied to return soil moisture to a level just below field capacity. In practice, this is not strictly true, as will be explained later.

In summary, irrigation is about keeping soil moistures between the stress point and field capacity, so that growth is not limited.

2.2 MEASURING CROP WATER USE

Answering the basic question of how much water crops need and when depends on understanding crop water use. Without knowing or being able to estimate what the current moisture status of the soil is, or whether the crop is under stress or likely to be under stress in the near future, it is impossible to irrigate efficiently.

There are three fundamental ways of measuring crop water use, namely;

- soil moisture measurements;
- plant water measurements; and
- evapotranspiration measurements.

2.2.1 Soil Moisture Measurements

Measuring soil moisture is a well-recognised method of estimating crop water use and is highly recommended. It allows you to determine how much water to apply, and with some knowledge of stress points for a crop, when to apply that water.

There are a number of methods available to farmers for measuring soil moisture.

Hire a consultant
One of the easiest ways is to employ a specialist to measure soil moisture readings for you. The specialist can also tell you when to next irrigate and how much water to apply.

However, some farmers prefer to do things themselves, and other options are available.

Observe and feel
This is the most basic method of using a spade to dig a hole to check subsurface soil moisture visually and by feel. It is quick, easy and low cost. However, it is not precise and it takes time for farmers to gain the experience to interpret the results.

Oven drying
This involves taking a sample of soil from the field (25-50 g), weighing it and drying it in an oven (usually a microwave oven), and then weighing it.

The gravimetric soil moisture is calculated as follows:

$$\textit{Soil moisture} = [(M_w - M_t)/(M_d - M_t)] - 1$$

where
M_w = weight of wet soil in the container
M_t = weight of the empty container
M_d = weight of dry soil in the container

Multiplying by 100 will give the percentage of water in the soil.

Although this method is accurate, it is time consuming, and requires a soil sample to be taken from the field each time. It also doesn’t tell you how much of the water in the soil was available for plant use, as plants cannot extract water to the point of making the soil oven dry.

Indirect methods of soil moisture measurement

In these methods, a meter or a device is used to measure a physical property of the soil that can be related to the soil moisture content.

Some of the methods in common use in New Zealand are:

- Tensiometers;
- Neutron Probes;
- Aquaflex Cables;
- TDR;
- Electrical Resistance Meters;
- Capacitance Meters.

Some of these devices are used to take readings manually, while others record soil moistures on a continuous basis. Low cost devices such as tensiometers are normally used by farmers, while more expensive devices such neutron probes and TDR are normally used by irrigation consultants as part of a soil moisture scheduling service, although some farmers do use these methods. Each has distinct advantages and disadvantages, and these should be discussed with an irrigation expert.

As with oven drying, most soil moisture measurement devices can give you the water content of the soil, but they do not tell you how much of that water is available to the plant. Tensiometers give an indication of how freely water is available to plants, but do not directly tell you how much water is available. However, guidelines are available to tell you how dry soils can get before plants come under moisture stress. Consult an irrigation expert or advisor for this information.

2.2.2 Plant Measurements and Methods

The general idea behind plant measurements is to measure the water status of the plant rather than the soil. The plant is the link between the soil and the atmosphere, and its water status can give an indication of when to irrigate.

Some of these methods are destructive, that is they require a sample of the plant to be removed for testing. Other methods involve fixing sensors to plants. Because individual plants are measured, these methods are more commonly used for orchards and tree crops. More broad-band methods such as remote sensing measure plant water status over a larger area of crop, and are more suited to pasture or field crops.

Examples of plant measurement methods are:

- Leaf Water Potential (Pressure chamber);
- Heat Pulse Method;
- Stem Diameter Measurement;
- Stomatal Resistance Methods;
- Microwave Measurements;
- Infrared Thermometry (Crop Water Stress Index).

Some of these methods are not commonly available commercially, and tend to be used more for scientific experiments. However, there may be farms or orchards where one of these methods is appropriate.

These methods give the water status of plants and therefore give you a guide as to when you should irrigate. They do not tell you how much water needs to be applied to replenish the soil water. If these methods are used, they need to be used in conjunction with some knowledge of soil water content and soil water holding capacity.

2.2.3 Evapotranspiration Measurements and Methods

Evapotranspiration (ET) is the total water lost by direct evaporation from plants and the ground surface and water transpired from plants. It is a way of estimating how much water has been taken from the soil, and therefore how much irrigation is required. Water budgets are used to calculate soil moistures indirectly by adding rainfall and irrigation (the amount of water applied to the soil) and subtracting ET (the amount of water taken out of the soil) to determine soil moisture status.

The most common methods of determining ET are:

- Weather Stations;
- Evaporation Pans;
- Lysimeters.

In New Zealand, ET figures calculated from weather station data are commonly presented in local newspapers during the irrigation season. Farmers may also purchase their own self-contained climate stations and calculate ET on their farm.

Evaporation pans (e.g. Class A Pans) are not widely used in New Zealand by farmers, although some irrigation resource consents now specify that pans be installed and used to schedule irrigation.

Lysimeters are more commonly used in scientific studies because they can measure ET directly.

2.3 WATER METERS

Knowing how much water an irrigation system uses is an important precursor to effective irrigation management, and is vital to using the recommended indicators in a meaningful way. Many of the indicators have a water quantity or flow rate component, (e.g. production per unit of water used, profit per unit of water used), and unless water use is measured, it will not be possible to calculate these indicators. In addition, measured flow rates or volumes may also be required to satisfy resource consent conditions.

The recommended method for measuring irrigation flow rates or volumes is to use a water meter. The types and quality of meters varies between brands, so a meter that meets or exceeds BS, AWWA, ISO and DIN standards is recommended. An accuracy of 5 percent should be easily attainable for water meters operating in pressurised systems, while an accuracy of 10 percent is probably more realistic for surface water systems.

For any pumped system, an alternative to measuring flow using a water meter is to relate the quantity of water pumped to the units of electricity used. This method requires volume of water used to be measured by a water meter and noting the electricity used for a given length of time. Volumetric water use can then be directly calculated from units of electricity used. Flow rates can also be calculated by dividing the volumes of water used by the run time of the system. An hour meter on the pump switch-gear is necessary for this.

Using electricity use to calculate water use is accurate only if the operating conditions of the pump or irrigation system do not change significantly.

For systems pumping from a bore, a seasonal lowering of water levels will often cause inaccurate readings. Pump wear will tend to lower efficiency and change the readings. Having the irrigators in different positions, or running blocks at different flow rates will also render the values inaccurate.

A water meter should be fitted in preference to using electricity readings.

Where irrigation systems are applying water at more than one location of the farm at the same time, e.g. for multiple irrigator systems, a water meter on each irrigator is recommended for optimum management.

3 Planning New Irrigation Systems

3.1 WHETHER TO IRRIGATE OR NOT

Although irrigation has many benefits, whether to irrigate or not is primarily an economic decision. The benefits of irrigation must increase income enough to cover the costs of purchasing, installing, operating, and maintaining the irrigation system and provide an acceptable return on investment for it to be sustainable.

A well-designed and managed irrigation system increases yield. As yield is one of the major determinants of profit, the impact of irrigation on expected profit and profit variation over a number of seasons needs to be assessed. Assuming that product prices and other input prices don't change, the increase in yield obtained through irrigation translates into increased profits. To obtain the net increase attributable to irrigation, the capital and operating costs of the irrigation system should be subtracted from the income arising from increased yield. If the costs are greater than the increased income, then perhaps irrigation should not be implemented. If increased income is significantly higher than the additional costs, then irrigation is probably worthwhile.

In New Zealand, irrigation is supplemental to rainfall, and the higher the rainfall, the lower the marginal return for irrigation. The difficulty with rainfall is that in many areas it is unreliable, causing high variability in annual yields and profit. With irrigation, yield variability is reduced significantly. Risk reduction is one of the main benefits of irrigation, as it reduces the risk of low yields.

All things considered, risk, however, does not necessarily decrease with irrigation. Risk may be increased in the long term by the decision to irrigate. Irrigated farms are subject to higher costs, and the investment in irrigation may expose the farm to higher financial risks. In addition, legislation may change affecting the cost of capital, access to water may change, increases in energy costs may exceed the increase in product prices, and so on.

Each case must be considered on its merits. Qualified farm and financial advisors should be consulted to determine the economic feasibility of irrigation.

3.2 DESIGN OF NEW SYSTEMS

An irrigation system must meet farmers' goals. The design of the system is one of the key determinants of whether that system has the potential to reach those goals.

To irrigate efficiently and sustainably, the irrigation system must be designed to be physically capable of meeting the needs that are identified. There is no point in making a decision to apply a given depth of water if the irrigation system is not physically capable of applying that depth. Likewise, there is no point in applying a given depth of water so inefficiently that the crop is only able to use a small proportion of the applied water.

In designing new systems, there are a number of basic design questions that need to be answered relating to water supply, application depths and rates, layout and equipment selection.

Relating to the water supply and irrigation system capacity, typical questions are:

- How much water is needed?
- What maximum supply rate (system capacity) is required?
- Where is the water going to come from?
- How much water is required per season?
- Is storage necessary?
- What consent conditions are likely to be imposed?

Having dealt with the issues relating to the water supply, the operation and management requirements for the system need to be addressed.

- What range of application depths should the system be able to apply?
- What range of return intervals can be accepted?
- What application rate is acceptable?

Finally, the system needs to be designed and irrigation equipment selected so that the system is capable of meeting the above requirements.

3.2.1 Water Supply/System Capacity

The water supply is the heart of any irrigation system, and is often the controlling factor in irrigation feasibility. It determines the area of crop that can be irrigated effectively, and has a large influence on the profitability of irrigation.

Although a number of community based schemes are in existence, water supplies for irrigation in New Zealand are developed primarily by individual landowners. Most farmers do not have the luxury of a choice of supplies. Often, only one choice exists realistically. This may be from groundwater, streams, rivers, harvested into storage, or part of a wider community based scheme. Other sources include municipal supply, sewage, and industrial wastes.

Locating a water supply may be an easy task if a stream or river is available, or if proven groundwater exists. However, a guaranteed supply is not always available.

River diversions are usually a simple method of obtaining water, and are often the cheapest, but river flows are subject to wide natural variations, and storage may be required to improve reliability of supply. Abstraction from rivers is controlled by legislation, and reliability of supply needs to be assessed. Groundwater is, in many situations, a more dependable source of water than river diversions. It is a form of natural storage that does not suffer from evaporative losses. However, the cost of lifting the water to the surface can be a major constraint to intensive use by individual farmers.

A water supply has an initial cost of development, and an ongoing cost for delivery. The ongoing cost for delivery is normally an energy cost, and conserving water and energy is important in maintaining a sustainable irrigation system.

Generally, surface supplies and groundwater supplies in New Zealand fluctuate significantly during the irrigation season, and are replenished by rainfall. When annual withdrawals from groundwater systems exceeds replenishment, water levels fall. Lower water levels increase pumping costs, and can make abstractions difficult or impossible. Energy requirements for pumping will affect irrigation costs, and profit. Some knowledge, therefore, of water supply reliability is required. Just because the water is easily available today does not mean it will be as freely available tomorrow.

3.2.1.1 Quantity of water required

An approximation of how much water is needed can be calculated as follows:

$$\text{Flow rate (in } m^3/h) = \frac{10 \times A \times d}{H}$$

where A = area irrigated in hectares
d = gross daily depth of water required in millimetres
H = number of hours of irrigation per day

An alternative way of calculating the flow rate taking into account the actual gross application depth and the rotation or cycle time is:

$$\text{Flow rate (in } m^3/h) = \frac{10 \times A \times D}{H \times F}$$

where A = area irrigated in hectares
D = depth of water applied in millimetres
H = number of hours of irrigation per day
F = cycle time or return interval in days

The factors d (or D) and F can be obtained from local irrigation specialists or Regional Councils. The factors A and H can be varied according to farmers' needs.

Any water requirements for frost protection, temperature control or leaching must also be taken into account.

Irrigation specialists take a number of factors into account when determining gross irrigation requirements. Some of these factors are the amount of water used by the crop (which depends on crop type and climate), effective rainfall, soils, carry-over soil moisture from winter rainfall, risk of not meeting soil moisture deficits and irrigation efficiency. A dependable water supply cannot be based on average requirements, as the supply would meet the needs of the crop only half the time if the average were used. High value crops may justify a water supply that will fully meet the needs of the crop nine years out of ten, while with low valued crops it may not be economical to supply total needs in more than five years out of ten. Each case must be evaluated individually.

3.2.1.2 Water quality

Water quality is important in evaluating a water supply. In general, water quality in New Zealand is very good, but in some areas there are problems.

Impurities carried in solution or in suspension determine water quality. Rainfall and snowmelt picks up impurities and silt as the water flows over the ground surface to streams. Water in streams and rivers pick up additional impurities. Runoff and excess irrigation may pick up nitrates, pesticides and other soluble compounds that could cause the water to be unsuitable for irrigation.

Whether water of a certain quality is acceptable for irrigation depends on climate, soils, crops grown, and depth of water applied. In general, water quality problems are higher in shallow groundwater areas, in streams during low flows, and in the downstream reaches of streams. Stream pollution from industrial wastes, and tide and wind conditions affect the quality of irrigation water. Brackish water is contaminated by acids, salts and organic matter.

Unless you are sure that water quality is satisfactory for irrigation, have the water analysed.

3.2.1.3 Location of supply

Location of the water supply has a major effect on the design layout, cost and operation of an irrigation system. Many irrigation systems have ended up being more expensive, both in terms of capital cost and in operating costs simply because the supply location had been chosen inappropriately. A common mistake is to place a well close to a roadway to give easy access to an electricity supply without considering the hydraulic efficiency of the system.

In many instances, location may be fixed by local conditions and be beyond your control. If there is a choice, *the supply should be located at the point that will give the lowest estimated cost of delivering water to each part of the irrigation system.*

If the water supply is to be pumped for surface irrigation, it is usually located at the highest point in the field, although in some systems it is cheaper to pump small quantities of water to localised high spots than it is to pump all of the water to the highest point. If the water source is a well, it will be necessary to lift all water to the highest point to supply the surface irrigation system. Again, it may be advantageous to have the well near to, but not at, the highest point to minimise pumping costs.

If the supply is a well, and the irrigation system is pressurised, there is generally much more flexibility in location. Although in some places the location depends on the aquifer, in most cases it is possible to locate the well at the optimum point.

On flat ground, the well should be placed near to the centre of the land to be irrigated. This results in the lowest pipeline cost because shorter runs and smaller pipe diameters can be used. If the property is sloping, the well should be placed towards the high end of the property. However, depending on the degree of slope and length of run, the highest point is not usually the optimum location.

Sometimes, more than one well is required to feed into a single system. Proper location of each well is vital to the cost and the long-term operation of the system. Multiple water supply systems can be hydraulically complex, and experts should be consulted.

The best advice is to have a number of options designed and costed for a range of well positions **before** the wells are drilled.

Remember, you pay for electrical installation costs once; you pay for design inefficiencies for the life of the system.

3.2.2 Application depths and rates

The three main questions that need to be answered when designing an irrigation system are:

- What depth of water should the system be capable of applying?
- How often should this depth be able to be applied?
- At what rate can the water be applied?

The key requirements of the system are to have the ability to match application depths to soil moisture deficits, to ensure that application rate does not exceed soil infiltration rate, and to apply water as uniformly as possible.

Each of these factors has a significant effect on the capacity and on the efficiency of the system.

3.2.2.1 System capacity (application depth and return interval)

At the design stage, the most important factor is to ensure that the irrigation system has the physical capability to apply the depths of water required to satisfy soil moisture deficits. Physical capability refers to the minimum and maximum depths the irrigation equipment is capable of applying, and the time between irrigation applications. The combination of application depths and the time between irrigation applications determines the overall capability of the irrigation system, and is known as **system capacity**.

System capacity relates to the maximum depth of water than can be applied by the system in a given time, and is normally specified in mm/day or mm/week, or other similar units. The capacity of the system must be sufficient to irrigate at a level that equates to the risk that the farmer is willing to take. In most circumstances, it is impractical and uneconomic to design systems to meet the worst case conditions that may arise.

Usually, irrigation system capacities are determined in one of three ways.

The first and perhaps the most common method is to use Regional Council water allocation guidelines. A council will allocate a given amount of water for irrigation for specified crop groups, and the irrigation system is designed to utilise this amount of water at peak capacity. Examples of the types of allocations in New Zealand are 5 mm/day, or 35mm/week, or 250 m^3/ha/week. Consult your local Regional Council for the figures in your region. Regardless of how the water is allocated, each type can be converted to applying a given depth of water in a specified time.

The second method is to design the system to use the available water, where the capability of the water supply is lower than the council allocations. As an example, assume a well has the capability to be pumped at 150 m^3/hr, and that you wish to put in an irrigation system to irrigate 100 hectares. If you pump for 24 hours a day, this equates to 3600 m^3/day, which is the capacity to apply 3.6 mm/day over the 100 hectares. This is the same as 25.2 mm/week or 252 m^3/ha/week.

The third method is to consider the risk of not meeting the full water demand of the crop during peak ET periods, and select a system capacity according to that risk. If you are not prepared to take any risk for a high value crop, you must use a system capacity that takes into account the maximum ET period of the season, irrigation efficiency, the readily available soil moisture, and the irrigation cycle time, so that you have the capability to keep soil moisture above the stress point at all times. For lower values crops, you may decide to risk not meeting the full demand of the crop during peak ET periods, accepting that at times soil moisture will fall below the stress point and cause a reduction in yield.

For good irrigation management, a range of application depths may be required. The extent to which farmers can vary the depth of water applied will depend on their irrigation systems. Automatically controlled systems normally provide the ability to easily change application depths. Surface irrigation systems and some sprinkler irrigation systems do not provide this flexibility. Although most travelling irrigator systems have a constant flow rate, changing the speed at which the irrigator moves over the paddock will vary the application depth. Some irrigation systems can move at any speed within their range and therefore are very flexible in the depths of water they apply. Other systems have a number of set speeds, and a change in flow rate as well as a change in speed may be required to apply a given depth.

It is extremely difficult to design practical borderdyke irrigation systems to apply less than 80 mm of water. If soil types dictate that less than 80 mm will be required, the use of borderdyke irrigation will result in losses to drainage regardless of how well it is managed. On higher water holding capacity soils, applying 80 mm of water may well be acceptable with borderdyke irrigation.

On light soils that are irrigated with sprinkler irrigation, low application depths may be required for efficient irrigation. Some sprinkler irrigation systems are not capable of applying small depths of water, and this must be considered at the design stage.

For travelling irrigator systems, the ability to stop the irrigator moving and turn it off at the end of a run has some advantages, as changing run speeds, for whatever reason, will change the time required to finish the run. The alternative is to close the system down on a time basis and hope that the irrigator is at the right place at the right time. However, this approach can waste water or fail to fully water the end of a run.

Required application depths depend primarily on soil water holding capacities and crop rooting depths. A range of required application depths should be specified for different soil and crop types so that an irrigation system capable of meeting the needs can be selected.

3.2.2.2 Application rate and infiltration rate

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

In sprinkler irrigation systems, application rate is governed by the flow rate and wetted coverage of the sprinklers. It must take into account the overlapping patterns of sprinklers.

Ideally, irrigation systems should be selected so that the average application rate of the system does not exceed the infiltration rate of the soil. Systems that apply water at rates greater than the soil can absorb it cause surface redistribution of the water. Water tends to run from the high spots to the low spots in the field. This means that the high areas receive less water than they should and the lower areas receive more than they should resulting in losses to drainage in the low points and possible loss of production on the high points. Excessive runoff can result in water flowing off the irrigated field and possibly off the farm altogether.

Excessive application rates can therefore be reflected in a number of indicators, particularly daily percentage of irrigation water flowing onto the farm that is stored in the root zone, daily visual assessment of the amount of surface runoff, and a number of the production indicators, such as profit per unit of water used.

Application rates of irrigation systems tend to be fixed according to the type of system and the design parameters. Although it is possible in some cases to reduce the application rates of systems by reducing operating pressure, nozzle sizes, or by changing the type of sprinkler on sprinkler irrigation systems, this is rarely done. It is better to ensure that systems with the correct application rates are selected at the design stage, rather than trying to change the system later.

Average application rates for irrigation systems are relatively easy to measure or calculate. It is more difficult to make an assessment of soil infiltration rates. Guidelines do exist, and soil experts can be consulted. In the absence of expert advice, infiltration rates may be measured using soil infiltrometers, or a visual interpretation based on irrigation performance on similar soils may be used. Be aware that soil infiltration rates change over time. The infiltration rates of well-structured irrigated soils can be considerable higher than on previously unirrigated soils of similar types. A visual measure of surface runoff may well indicate this.

3.2.2.3 Application uniformity

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

The reasons for poor uniformity of sprinkler irrigation systems include:

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

The effects of poor uniformity may be difficult to detect with any of the indicators proposed. In extreme cases, reductions in yield become apparent in underwatered areas.

However, detecting overwatering due to poor uniformity, especially if average application depths and application rates are correct, is extremely difficult.

Physically measuring application depths is one way of doing this. A number of rain gauges placed under sprinkler irrigation systems can give a visual indication of application depths and uniformity. These measurements give results that depend on the conditions occurring at the time, and a series of tests may be required to give an accurate representation of system performance. Measuring application depth and uniformity under surface irrigation systems is more difficult.

Overall, poor application uniformity means that more water is needed per unit of production. Poor uniformity can be detected in the total quantity of water needed in a season as more water is used than would otherwise be necessary to produce a given yield.

As with application rate, the options to physically improve uniformity are limited once a system is designed and installed. Sprinklers may be exchanged for more suitable models, system operation may be changed to reduce pressure variations, sprinkler spacing may be modified, and irrigation may be turned off in windy conditions, but beyond that very little can be changed.

Careful irrigation management can help to reduce losses to drainage. By applying smaller depths of water and not bringing soil moistures back to the full point, the variations in application depth caused by the non-uniformity can be absorbed. Again, there are limits to what can be done. The best solution is to choose the most appropriate system at the time of purchase. The systems that give high application uniformity under ideal (design) conditions will usually outperform poorer systems under adverse conditions.

3.2.2.4 Calculation of application depth and return interval

To calculate the application depth and return interval for design, the following example is given to illustrate one of the methods described above.

Lets assume that you are using Regional Council recommendations for your system capacity, and in your situation you can use 330 m^3/ha/week.

You wish to irrigate 84 hectares with one irrigator, and will be operating your system for 23 hours per day at the peak of the season. Each irrigator run will irrigate 6 hectares at a time.

Your soil type is a medium silt loam with a readily available soil moisture content in the root zone of 80 mm. Ideally, you want to allow a margin for rainfall and application uniformity to improve your efficiency, so you would like to design your system to apply about 60 mm in an application.

$$\text{Pumping rate (m}^3\text{/hr)} = \frac{\text{System capacity (m}^3\text{/ha/week) x Area (ha)}}{\text{Daily run time (hours/day) x 7}}$$

$$= \frac{330 \times 84}{23 \times 7}$$

$$= 172$$

$$\text{Application depth (mm)} = \frac{\text{Pumping rate (m}^3\text{/hr) x Daily run time (hr/day)}}{\text{Daily area irrigated (ha/day) x 10}}$$

$$= \frac{172 \times 23}{6 \times 10}$$

$$= 66$$

$$\text{Rotation time (days)} = \frac{\text{Total Area (ha)}}{\text{Daily area irrigated (ha/day)}}$$

$$= \frac{84}{6}$$

$$= 14$$

The gross application is about 66 mm, which is acceptable for a soil with readily available soil moisture of 80 mm. The net application is probably about 75 percent of this, i.e. 50 mm or 3.6 mm/day on a 14-day rotation.

If you were in the situation where your soil was very light and only had a readily available soil moisture of 40 mm in the crop root zone, then applying 66 mm gross would result in a significant percentage of this water draining through the soil profile. In this case, you would need to apply less water by operating your irrigator at higher speed so it applied a smaller depth (perhaps shifting twice daily at the peak of the season). An alternative is to use two irrigators so that each irrigator applied 33 mm on a run. This is possible because each irrigator is watering half the number of paddocks, and therefore needs to apply half the amount of water.

3.2.3 Other Considerations for Irrigation System Selection and Design

3.2.3.1 General layout

In conceptual terms, one of the key factors is to design the farm around the irrigation system, not the irrigation system around the existing internal farm layout. This may mean moving fences, removing shelterbelts or trees, and perhaps changing the position of drains or water races, or putting in new accessways. Irrigation should take priority as it is a long-term investment.

3.2.3.2 Surface runoff

As stated earlier, surface runoff of water can result from applying water at excessive application rates or with very poor application uniformity. As the infiltration rate of soils tends to decrease with the time of irrigation, the likelihood of surface runoff increases with increasing application depths. Surface redistribution or runoff is less likely when small depths are applied.

Water that runs off the area being irrigated is not able to be used by the crop regardless of the crop and soil conditions, and is wasted. The benefit of the water applied is reduced, and production per mm of water applied is reduced.

Losses from micro-sprinkler, mini-sprinkler and drip irrigation due to surface runoff are normally less of a problem, although they can occur in poorly managed systems.

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

Measuring these losses can be difficult. A visual interpretation is all that is possible in many cases.

3.2.3.3 Effects on soil

The breakdown of soil particles at the soil surface is mainly relevant to high-volume sprinkler irrigation. This is caused by the impact of the irrigation water on the soil particles causing either movement of the particles or the breakdown of the soil into smaller particles. The heavier the crop cover, the less likely there will be a problem.

The main issues are water droplet size, intensity, and angle of contact of the water stream with the soil surface, which are functions of the system design, operating pressure and nozzle sizes.

To reduce problems with soil breakdown and movement, it may not be possible to use particular types of irrigation systems in some circumstances. If a problem with soil movement and breakdown is occurring, it is difficult to modify the system to prevent it. Running smaller nozzles at higher pressures may help to reduce droplet sizes, but beyond that, not much can be done.

This illustrates the importance of selecting the right machine for the job at the design stage of the process.

The effects of system design on topsoil depth are minimal. However, some soils are highly susceptible to water erosion. Unless a good crop cover can be established before irrigation, these soils should not be irrigated with flood irrigation.

3.2.3.4 Wastewater irrigation

Wastewater from agricultural enterprises, such as piggeries or dairy sheds, can be a valuable nutrient resource to a farm. There is a considerable fertilising benefit to be gained when applying wastewater to pasture and cropping land. Wastewaters contain nitrogen, phosphorus and potassium. They may also contain other elements such as calcium, magnesium and sulphur as well as other trace elements beneficial to soils, pasture and crops.
Unlike clean water irrigation, wastewater irrigation may need to occur when the soil is not in a moisture deficit situation, and for this reason, some of the design aspects differ from those required for clean water irrigation.

There are a number of factors that should be taken into account when selecting a wastewater application site such as:

- soil types - permeable soils are preferable;
- depth to groundwater - areas with deep water tables are preferable;
- topography - level sites, without humps or hollows which may generate ponding or runoff, are preferable;
- proximity to surface waterways;
- proximity to neighbouring dwellings, roads and other public places should be as far as possible;
- accessibility - the application area is best placed close to where the wastewater is generated. This reduces the capital cost and the operation of the system is easier to monitor and system failure can be quickly identified.

Well-designed spray application systems operate with minimal wastewater spray drift, ensure even application, require minimal manual shifting and are readily expandable.

Pumps should be selected that:

- have duties to match the required flow rate and operating pressure of the system;
- include seals and bearings designed to withstand wastewater conditions;
- are designed with large clearances to minimise blockages;
- are easy to maintain; and
- are constructed from non-corrosive materials.

Normal clean water pumps are not suitable for pumping wastewater. Electric motor driven pumps are preferable.

The delivery pipeline should utilise swept ‘bend’ fittings in preference to sharp ‘elbow’ fittings’. Pipe velocities should not exceed 2 m/s to reduce frictional losses and water hammer, and should not fall below 0.7 m/s to prevent silting of solids.

Hydrants provide for connecting the irrigator to the buried pipeline. Hydrants with ‘T’ section joins are not suitable as suspended solids can settle in the dead section of the mainline causing blockages.

Travelling irrigators or sprinklers especially designed for wastewater application should be used. Rubber sprinkler nozzles are preferable as they expand if a stone or any solid material comes through the delivery line and will not block as easily. To reduce aerosoling effects low-pressure spray nozzles (i.e. 100 kPa to 300 kPa) with large orifices (i.e. between 8 mm and 16 mm) should be used. Travelling irrigators have a number of advantages over stationary and multiple sprinkler systems.

It is possible to use an existing clean water irrigation system if the wastewater is sufficiently diluted.

If the application of animal wastewater is not permitted by a regional rule in the Regional Plan then a discharge permit would be required for the activity. To obtain this information you should contact your Regional Council or Unitary Authority.

To protect groundwater and to minimise nuisances and odour problems, Regional Council regulations tend to restrict the wastewater nitrogen loading onto the land, and give buffer distances from waterways and public places.

3.2.3.5 Production/Unit of Irrigation Energy Input

The energy input into irrigation systems in New Zealand normally refers to electricity required for pumping, although centre-pivot and lateral move irrigators also require an additional energy source for propulsion.

Choosing the right pump for the application is vital to minimising energy use. There are significant differences in the maximum pump efficiencies of different pump models. Also, electric motor efficiencies can vary between models. This means that there can be significant differences in energy use between pumps that provide similar duties.

The lowest cost per cubic metre of water pumped generally occurs when the pump is being operated at a flow equal to or higher than the flow at the maximum efficiency point. Choosing a pump with an operating duty above the maximum efficiency flow will also result in less loss of irrigation system performance as the pump wears.

3.2.3.6 Production/Unit of Labour Used for Irrigation

The labour required to operate irrigation systems varies enormously. Fully automated systems can reduce the labour required for daily operation of the system to a few minutes per day. However, automatically controlled systems cost more, and depending on the system, can have a significant labour requirement for maintenance. The capital cost of automation should be weighed against the labour cost including maintenance to obtain a comparative cost.

3.2.3.7 Reliability of Irrigation Systems

To get the best out of an irrigation system, it is important that it is running to specification. All systems require repairs and maintenance, with some requiring more than others.

As systems age, the money and time spent on repairs and maintenance increases, and may become a significant part of the total running costs of the system. In addition, breakdowns can result in loss of production, particularly if they occur at the peak of the season.

When first purchasing an irrigation system, finding out how reliable the system is, how much maintenance is required, and how many years service can be expected from the system is recommended. Poor water quality due to sand, organic materials, precipitation of solids, and iron in the water can have a significant effect on system life and reliability. It is important that you choose system components appropriate to the quality of water.

Monitoring the number of hours lost per season due to system failure will allow the reliability of the system to be assessed, and provide guidance as to when the system or parts of the system should be replaced.

3.3 DESIGN CHECK/AUDITING

For new systems, an independent design check will help to ensure that the system will perform to specification, and should be carried out before the design is finalised. For existing systems, a design audit determines the capability of the system, and can identify limitations or problems in the system.

Many farmers do not know how well their irrigation systems are performing, how much water they are applying, or even whether their system is designed correctly. It is very difficult to tell by looking at the system. If you can see there is a problem, the situation is usually quite serious.

The cost of correcting mistakes or improving systems is easy at the design stage, but for existing systems can range from minor to extensive. It may not be cost effective to make changes to a poorly designed system, and a range of options may need to be considered. However, unless an irrigation system has the capability to provide acceptable performance, it will always be difficult to operate it in an efficient and sustainable manner.

3.4 INSTALLATION/TESTING/COMMISSIONING

All materials should be installed in accordance with the manufacturer's instructions.

In particular, attention should be given to pipe laying, installation of thrust blocks, and installation of pumps.

The irrigation system should be properly tested and instructions given on the correct operation and maintenance of all equipment.

3.5 DOCUMENTATION

It is very important that the designer/installer provides written documentation of the design and installation.

Specifications of the system should be clearly stated, and the results of testing and commissioning given.

Operation and maintenance requirements should also be documented.

4 Pre-Season Checks

4.1 WELLS AND PUMPS

The most common question asked about wells and pumps is whether or not they should be tested.

For irrigation systems with high system capacities, a small loss of pumping performance may not be an issue. For systems with limited system capacities, a drop in performance may be very serious indeed, because it could result in significant water shortages and yield losses.

If your pump and well was properly tested at the time of installation, and you have data to show that the current performance is close to specification, then the answer is probably no, you don't need to test it. Properly installed pumps that are pumping clean water can run for many years without problems.

If your system has dropped in performance, for example by failing to run the irrigation system at the correct pressures, then a pump and well test is recommended.

All wells and pumps deteriorate over time. The rate of deterioration depends on the age of the well and pump, water quality, screen type, and operating conditions. The loss of performance is usually a gradual process, and unless hard data through testing was provided at the time of installation, it can be difficult to know whether the performance has changed. It is also difficult to know which factors are contributing to loss of performance where this has occurred. Possible reasons are water level changes or aquifer depletion, pump wear, screen blockages, casing failure, or contamination.

Pump repairs can be kept to a minimum if these repairs are carried out while problems are small. Major failures, particularly with submersible pumps, can be expensive to correct.

Irrigation systems with water meters installed are relatively easy to test, and most irrigation or well drilling companies can do this. If a water meter is not currently installed, a test is still relatively easy, but a meter will need to be temporarily connected to the system, such as at the closest hydrant.

4.2 TRAVELLING IRRIGATORS

The Owners Manual, if provided for your irrigator, will give you guidance on what should be attended to before the irrigation system begins. Attention is usually given to lubrication, bearings, seals, tyre pressures, drag hoses, wire ropes, and structural aspects of the machine.

Pressure gauges, particularly those that have been subjected to large pressure variations, are often not accurate. A second gauge should be kept to test and compare the readings.

Pipes and hoses should be checked for foreign matter. Rabbits and birds often cause blockages, and foreign objects could cause serious damage to the drive units of travelling irrigators if allowed to pass through the system.

Leaks in pipes (particularly pipes on the ground surface) should be identified and repaired.

Sprinklers, nozzles and/or jets should be examined and repaired or replaced if necessary.

The system should be run to check sprinkler operation, application depths and travel speeds. Adjustment to lane spacings should be made if necessary.

4.3 HORTICULTURAL SYSTEMS

One of the biggest problems with horticultural systems is damage to lateral pipes and sprinklers, jets or drippers during harvesting and follow-on work. These must be repaired before the irrigation season begins.

If there is any likelihood of foreign matter in pipes, the system should be properly flushed out before any pressurisation of the system occurs.

Operation of solenoid valves and controllers should be checked and repaired if necessary.

4.4 SURFACE IRRIGATION (BORDERDYKE)

Borderdyke irrigation systems also need maintenance.

In particular, attention should be given to the condition of headraces to ensure that the full flow is able to reach all parts of the system without overflowing. Gates should be checked for damage, and to ensure they seal correctly.

Sills should be checked to ensure they are clear of debris, are level and at the correct height. Borders, if severely damaged, may require reforming.

Headraces should be fenced, and periodically grazed with sheep (not cattle) to keep them clean.

4.5 WASTEWATER IRRIGATION SYSTEMS

Animal wastewater is abrasive and corrosive. The importance of preventive maintenance cannot be over-emphasised. Moving parts (pumps, hose couplings, irrigators and sprinklers) should be kept clean and well lubricated.

Regularly

- Make sure that the spray application system is not spraying wastewater into the water troughs.
- Waterways should be checked regularly to ensure that wastewater is not moving into the water.
- Clean and clear any wastewater stone trap and gratings.
- Check that the float switches are clear and working.
- Grease the applicator.

- Check that the sprinklers are not blocked or damaged.
- Flush clean water through the delivery pipeline and sprinklers to keep them from blocking. If the equipment is idle for more than one week flush it with clean water prior to close down. This will prevent the wastewater solidifying and blocking the system.

Six Monthly to Annually

- Strip down the pump for oiling and cleaning.
- Check the pump seals as these are the components most susceptible to wear.
- General maintenance of the storage facility such as removal of sludge and spraying of any weeds growing on storage ponds.

4.6 CARRYING OUT FLOW CHECKS

As stated earlier, knowing how much water has been used is vital for effective irrigation management, and some form of water metering is necessary to use the performance indicators.

Measuring flow rates or volumes allows you to set baseline indicator values and to carry out an ongoing check of the capacity of your system. In particular, you can use water meters to:

- Check that the system is drawing the amount of water you expect;
- Compare performance with the design specifications;
- Check daily variations in quantity or flow rate over the system due to changes in pressure;
- Determine limitations in irrigator positions;
- Determine unacceptable pressure variations due to pipeline sizes, wrong pump duty, or elevation effects;
- Compare performances with resource consent conditions; and
- Monitor the amount of non-irrigation time or downtime in a cycle.

In the longer term, flow or volume measurements allow you to:

- Determine how system performance has changed over time;
- Help pinpoint reasons for changes. Possibilities include pump wear, water supply degeneration, well levels dropping, screen blockages, channel deterioration and diversion problems.

Without making these measurements, you may not be aware that a problem exists.

The accuracy of measurement needs to be considered. An accuracy of 5 percent should be attainable for water meters operating in pressurised systems, while an accuracy of 10 percent is probably more realistic for surface water systems.

Where irrigation systems are applying water at more than one location of the farm at the same time, e.g. for multiple irrigator systems, a water meter on each irrigator is recommended for optimum management.

5 Planning the Season's Irrigation

This is probably the most important aspect of irrigation after design, and one area that many irrigators give insufficient time to.

In addition to setting goals, farmers should prepare an **irrigation strategy** or management plan that describes how they are going to manage their irrigation systems on a daily basis to achieve the targets or goals they have set out. The irrigation strategy should include a method which will be used to determine where to irrigate each day, and how much water to apply at each irrigation, taking all factors into account.

Targets for indicator values should be set, so that they can be monitored during the irrigation season to determine progress, and reviewed either during the season or at the end of the season.

The plan must be written down so that it can be referred to during the season, and reviewed at the end of the season.

The strategy used for every farm will be different, but there are some basic principles that all irrigation farmers should be aware of. To help you plan an irrigation strategy and set targets for indicators, some of these principles are described below.

5.1 MAXIMISING APPLICATION EFFICIENCY

No irrigation system applies water uniformly over an area, except perhaps small basin irrigation where basins are filled rapidly. Borderdyke irrigation tends to apply more water at the top of the border than the bottom. Sprinkler irrigation, because of uneven sprinkler distribution patterns, tends to apply more water at some locations than others. Drip irrigation applies water in a small area.

Regardless of how uniformly the water is applied to the soil, varying infiltration rates, surface redistribution of water, variation in soil water holding capacities and crop root depths all contribute to some unevenness of water storage in the soil and water use by the crop.

In theory, the most efficient time to irrigate is when the soil moisture is at the stress point, and the correct depth to apply is the depth that returns the soil moisture to field capacity.

However, this approach does not take into account the non-uniform nature of irrigation applications, plant water use, and soil moisture holding capacities of the soil. If the theoretical depth is applied, some areas get over-watered, which results in losses to drainage. Likewise, some areas get underwatered, and at the end of the irrigation cycle, just before the next irrigation, these areas may be below the stress point and suffer some yield loss.

The most efficient practice, therefore, is to irrigate when soil moistures are a few percent above the stress point, and to apply enough water to bring the soil not back to field capacity, but a few percent below this level.

For example, if a soil holds 100 mm of water between the stress point and field capacity, that is the soil in the root zone of the crop has a readily available soil moisture of 100 mm, then irrigating when the deficit is at say 85 mm and applying 70 mm of water to finish with a soil moisture deficit of 15 mm, will result in more efficient use of water than irrigating at a deficit of 100 mm and applying 100 mm. The irrigation trigger level in this example is 85 mm, not 100 mm as would often be used.

What happens with this approach is that the areas that would normally have been over-watered end up with soil moistures near field capacity. Because of the higher trigger level, areas that would normally suffer some moisture stress remain above the stress point.

This simple example illustrates the advantage of irrigating with smaller applications, but more often. However, there is a cost. Systems have to be designed to operate on shorter cycles, and for non-automatic systems, this may cost more. This should be addressed at the design stage of the process.

5.2 OPTIMISING THE USE OF RAINFALL

An irrigation strategy that applies less water more often also has a major advantage in that it allows rainfall to be used more effectively.

The closer that soil moistures are to field capacity, the more likely that rainfall will be lost to deep drainage. Conversely, the drier soils are, the less likely that rainfall will drain below the root zone of the plants. Given that the total water used by a crop in a season, i.e. the sum of irrigation and rainfall, does not vary much, the more rainfall that can be used, the less irrigation that will be required. Using rainfall efficiently reduces irrigation costs.

In theory, the most efficient use of rainfall would occur if soil moistures were retained at a little above the stress point by applying very small depths of water. This would leave the soil as dry as possible without causing any crop yield loss. This is only possible with some automatically controlled horticultural irrigation systems, as it requires daily irrigation and a system capacity to meet the demand of the highest ET days. Irrigation systems are not normally designed to this level of capability.

For large field sprinkler irrigation systems, it is not realistic to design or operate the system at this level, and a compromise must be reached. There is a trade-off between irrigation efficiency and optimum use of rainfall with irrigation system capacity and cycle time. For well-designed systems, the approach of using a trigger level a little above the stress point and irrigating to just under field capacity is a reasonable compromise.

5.3 WATER SUPPLY RESTRICTIONS

Because of the way water for irrigation tends to be allocated and controlled by Regional Councils in New Zealand, whether restrictions will be imposed and if they are when that will occur, is often unknown at the start of the irrigation season.

For groundwater takes, restrictions are usually applied when groundwater levels reach predetermined minimum levels. When these levels are reached depends on many factors, such as whether there is any natural recharge, the amount of abstractions, the status of levels at the start of the season, etc. Some councils may be able to give an indication of whether restrictions are likely to be imposed, and perhaps when.

For takes from rivers or streams, abstractions are normally controlled according to river or stream flows, and when that is likely to occur depends on a number of factors, but is primarily dependent on rainfall.

The need for irrigation varies significantly between seasons because of rainfall variations. Some indication of the requirements for the coming season can be obtained from long-term weather forecasts, and in particular, the likely effects of El Nino or La Nina weather patterns should be noted.

Your irrigation strategy for the season is essentially risk management, and should take these factors into account. If a very dry year is forecast, you may decide at the start of the season to irrigate less area, or irrigate a larger area at the start of the season with the expectation that you will drop some areas out of the irrigation cycle later on.

If appropriate, you should allow for the worst case scenario of having no water at all during some parts of the season.

5.4 WHERE TO IRRIGATE

A strategy of where to irrigate during the season should be planned at the start of the season.

Whether a paddock needs irrigating or not depends on soil moisture levels in the paddock, the vulnerability of crops to soil moisture deficits and the time until the next irrigation of that paddock. A crop does not need to be irrigated if there is sufficient water stored in the soil to meet ET requirements and to keep moisture levels above the stress point until the next time irrigation is available. The stress point will differ between crops and will be higher for certain stages of crop development where plants are vulnerable to water stress.

The frequency at which a paddock can be irrigated is determined by water availability and irrigation system design, and must be taken into account.

As an example, you could use a very simple rule such as irrigating each crop as it comes up in the irrigation rotation unless moisture levels are above 70 percent. In other words, you only skip watering a paddock if the soil is still quite moist.

If system capacity or water supply is limited, you may set a priority system such as irrigating grain crops during head forming if moisture levels drop below 90 percent as a first priority. Next priority might be non-pasture crops if moisture levels could drop below 80 percent.

There are many alternatives and best use of the available water should be planned so that the main objective of maximising profit can be obtained.

5.5 WHEN TO START IRRIGATING EACH SEASON

One of the main decisions you have to make is when to start irrigating each season.

To make this decision, you should have a preseason plan, know your crops stress point, keep in mind your irrigation system's capacity and ability to keep up or catch up, and most importantly, measure soil moisture.

Soil moistures, because of winter rainfall, are normally at field capacity at the beginning of the growing season. ET rates are lower in the early part of the season, but soils can become dry without farmers realising it. When they do notice, it is often too late to catch up, and crop yields suffer. However, delaying irrigation for as long as possible is desirable, provided that it doesn't cause significant yield reductions.

There are a number of ways that you can decide when to start irrigating, some better than others. Possibilities include carrying out water budgets, inspecting crops, checking the soil, watch for neighbours irrigating, using weather forecasts, or using soil moisture measurements.

Using soil moisture measurement combined with ET predictions is the best method because it is more certain than any of the other methods.

The decision as to what depth to apply should be based on soil moisture levels in each paddock. After the irrigation, there needs to be sufficient water stored in the soil to meet plant ET requirements and keep moisture levels above the stress point until the next time irrigation can be applied. Some allowance (i.e. a soil moisture deficit remaining after irrigation) could be made to accommodate any rain that occurred in the interval between irrigations, and to improve efficiency.

As an example, assume that it is the 15th September, and you wish to calculate when to start irrigating your pasture.

Your soil has readily available soil moisture of 80 mm, and your irrigation system has the capacity to apply 5 mm/day, which is close to the maximum ET expected. The farm is divided into 10 paddocks and the irrigation system can apply 50 mm every 10 days. You have been told that the efficiency of your system is about 80 percent. Your soil moisture meter indicates that the soil currently has a 25 mm water deficit.

The ET rate in your area for the second half of September is 2.8 mm/day, and for the first half of October is 3.1 mm/day.

Gross depth applied	50 mm	(A)
Net application depth (80%)	40 mm	(B)
Current soil moisture deficit	25 mm	(C)
Deficit at stress point	80 mm	(D)
Current available soil moisture	65 mm	(E) = (D) – (C)

If irrigation does not take place, the soil moisture would be at the stress point in 22 days.

ET for September 15 days x 2.8 mm/day	42 mm	(F)
Remaining water at end of September	23 mm	(G) = (E) – (F)
Days to use water up in October 23/3.1	7 days	
Total days until stress point is reached	22 days	(7 October)

If you started irrigating in 22 days time, all paddocks would be at the stress point at the same time. Because your system takes 10 days to cover the farm, you need to start irrigating 10 days before the stress point is reached.

Starting date for irrigation, therefore, should be in 12 days time, i.e. on 29 September.

On this date, the remaining soil moisture in the first paddock will be 31 mm. If 40 mm net is applied, the soil moisture deficit remaining after irrigation will be 9 mm (80-31-40). This is because your soil can hold 80 mm of water. (If your soil could only hold 40 mm of water, some of the applied water will drain through the soil profile. Already 10 mm has been allowed for due to inefficiencies in the system, so potentially more will be lost. If your irrigation system can only apply a fixed depth of 50 mm gross, you will have to accept these losses. If, however, your system can apply smaller depths, for example by running the irrigator at a higher speed, the gross depth should be calculated and applied for each paddock until the soil is able to accept the full application.)

In this example, none of the paddocks will have been irrigated to field capacity. The first paddock will have a deficit of 9 mm after irrigation while the last paddock in the rotation will have a deficit of 40 mm after irrigation on 7 October.

There has been no allowance for rainfall in these calculations. In such a short time period (12 days), there is a high chance that rainfall will not occur. If it does, soil moistures should be measured again, and the calculations redone.

The strategy used in this example assumes that you wish to start irrigation as late as possible in the season, and have sufficient system capacity to keep up with the high ET rates later in the season. This strategy is often used for horticultural irrigation to maximise the use of rainfall and to maximise efficiency. If your system has a limited capacity, a different strategy should be applied, as described later.

5.6 IRRIGATING MID SEASON

Once you have completed one cycle, you have to decide when to start the next cycle. Assuming a strategy of irrigating as late as possible, the same process is applied again. This time, however, the soil moistures of the paddocks will all be different.

Using the above example again, assume that ET rates for the second half of October are 3.6 mm/day.

Paddock 1

Soil moisture deficit on 29 September after irrigation	9 mm
ET for remaining September 2 days x 2.8 mm	6 mm
ET in 1st half of October 15 days x 3.1 mm/day	47 mm
Deficit at stress point	80 mm
Remaining water on 15 October	18 mm
Days to use water up in October 18/3.6	5 days
Total days until stress point is reached	22 days

This means that Paddock 1 does not have to be irrigated for 22 days after 7 October, i.e. on 30 October.

Now, carry out the same calculations for Paddock 10, which was irrigated on 7 October.

Soil moisture deficit on 7 October	40 mm
Deficit at stress point	80 mm
Remaining soil moisture on 7 October	40 mm
ET in 1st half of October 8 days x 3.1 mm/day	25 mm
Remaining water on 15 October	15 mm
Days to use water up in October 15/3.6	4 days
Total days until stress point is reached	12 days

This means that the last paddock will have to be irrigated again on the 19 October. Again, because it takes 10 days from irrigating the first paddock until you can irrigate the last paddock, irrigation has to start 10 days before the last paddock will be at the stress point, assuming that no rain falls.

This means that irrigation has to start in Paddock 1 on 9 October, even though it has enough soil moisture to wait until the end of October to be irrigated again.

The same process should be repeated to determine the date for the next irrigation.

If soil moisture measurements are being taken, actual soil moisture deficits should be used in the calculations, rather than calculated deficits.

If heavy rainfall occurs, and all soil moistures are returned to field capacity, the process for timing the first irrigation should be used to determine when to start irrigation again.

If soils with different water holding capacities exist, or if crop water use patterns vary between paddocks, the calculations should be made for each paddock. The order in which paddocks are irrigated may need to change.

5.7 WHEN TO APPLY THE LAST IRRIGATION

In New Zealand, winter rainfall generally eliminates moisture deficits that may remain at the end of the irrigation season. Usually soil moistures are returned to field capacity by the beginning of the next season.

It makes sense therefore, to leave the soil as dry as possible at the end of the irrigation season. The difficulty is that you don't know when rain will fall and how much there will be.

The need for additional irrigation at the end of the season is best determined using a water balance worksheet that takes into account the predicted ET and an estimate of likely rainfall over the rest of the growing season, rather than just over the next irrigation cycle. In mid season, it is normally wise to assume that no rain will fall. This is not the case at the end of the season, because of the longer times involved.

As an example, consider the situation where it is the 1st of April on your irrigated dairy farm, and you need to decide whether any more irrigation is required this season, i.e. before the end of May.

Example calculation:

Current date		1 April
End of season date		31 May
Crop		pasture
Allowable soil moisture deficit		80 mm
Current deficit		20 mm
Water available		60 mm
Expected useful rainfall		50 mm
Total available water		110 mm
Crop needs based on average ET		
April	30 days at 2.5 mm/day	75 mm
May	31 days at 2.0 mm	62 mm
Total crop needs		137 mm
Net irrigation required		27 mm
Gross irrigation required		32 mm

In this case, one further irrigation is recommended, because it is likely that soil moistures will be too low by the end of May.

If this was a horticultural crop, and the crop required watering until the end of May, more than one irrigation may be needed, depending on the depth applied at each irrigation. If the system applied 10 mm per application, then perhaps three irrigations would be required.

This calculation should be made for each paddock in the rotation or each block in the orchard.

The current soil moisture depletion must be measured using soil moisture measuring equipment, or estimated using a water balance work sheet. There is some risk involved in estimated rainfall, but this can be adjusted according to the value of the crop, and the consequences of getting it wrong.

For high value crops, a rainfall amount that has a 90 percent chance of being equalled or exceeded could be used. It is extremely rare for no rain at all to fall in April and May. For lower valued crops, average rainfall could be used.

If an unusually dry situation did occur, irrigation can be restarted, but on systems with long cycles, catching up in all paddocks may be difficult.

5.8 SYSTEMS THAT APPLY LARGE FIXED DEPTHS

Flood irrigation systems such as borderdyke systems typically apply large amounts of water, and scheduling irrigation for these systems can be difficult. Many of these systems run on fixed rosters, and very little flexibility is available to farmers. When irrigation water is available, farmers tend to take it, because if they don't, the time until the next irrigation may cause soil moistures to drop to the point where serious production losses could occur.

For systems with some flexibility in watering time, irrigation scheduling is a trade-off between minimising crop water stress and minimising leaching or drainage. On high water holding capacity soils, losses to drainage could be minimal if irrigation is able to take place when soil moistures are at or near the stress point. On low water holding capacity soils, losses to drainage can be quite high, and difficult to avoid.

At the start of the season and after heavy rainfall, irrigation managers often irrigate early to prevent stress at the end of the cycle and accept more drainage at the start of the cycle soil moisture deficits are quite low. For subsequent irrigations, soil moistures tend to even themselves out.

There is no perfect solution to managing flood irrigation systems on light soils. System changes that reduce the depth of application need to be considered for significant improvements to be made.

5.9 WHAT TO DO WHEN IT RAINS

Irrigation gives a farmer control of the watering for a crop. Scheduling irrigation is easiest when it does not rain.

If rain falls during the middle of an irrigation cycle, and the amount of rain is enough to return the most recently irrigated paddocks back to field capacity, but not in the areas yet to be irrigated, the soil moistures will vary across the farm.

The approach that should be taken depends on the capacity of the irrigation system and whether or not the system can apply variable depths of water.

If the system capacity is limited and there is some difficulty in satisfying the soil moisture deficits, the rainfall may have been a bonus. Irrigation may be able to be turned off for a limited time, but soil moistures should be retained at or near to field capacity, so that when evapotranspiration exceeds the capacity of the system to apply water, the buffer in the soil keeps soil moistures above the stress point for as long as possible.

If the irrigation system can apply variable depths, irrigation can continue, and the depth applied is adjusted to the deficits remaining after the rainfall. Irrigation on each successive area will require progressively more water. Within one cycle, irrigation applications will return to the depths applied before the rainfall.

If the system cannot apply variable depths but is not limited in capacity, irrigation can be delayed until ET has used up the effective rainfall, and irrigation must then start again, with the full depth being applied. If 25 mm of rain fell, and average ET was 5 mm per day, irrigation could be delayed for 5 days and no more, even though the soil moistures in some paddocks would still be above the trigger level.

If the rain was sufficient to completely bring all areas back to field capacity, irrigation should proceed exactly as for the first irrigation of the season.

5.10 IRRIGATING IN WINDY CONDITIONS

Surface irrigation systems and drip or sub-surface irrigation systems are generally not affected by wind. However, sprinkler or microsprinkler systems can be seriously affected.

Wind affects irrigation in three main ways.

The first is by distorting the sprinkler application pattern so that water is applied very unevenly. Some areas receive more water than they should and some less, resulting in less efficient irrigation. The second is through evaporation of water in the air, on the crop surface, and on the ground surface. This water is lost and not available to the crop. The third is by physically blowing water away from the irrigated area.

The best solution is not to irrigate during windy conditions. Often it is less windy at night, so irrigation should be carried out at night. Irrigating at night also reduces losses due to evaporation. Some days, it may be better to turn the irrigation system off altogether. However, turning the system off reduces your effective irrigation system capacity. If your system has a limited system capacity, turning off may have serious consequences through crops being water stressed, and you may need to keep irrigating, even if it is very inefficiently.

If you are irrigating in an area that tends to be quite windy, it is preferable to design the system with some additional capacity so that you can turn off during windy periods and use the extra capacity to catch up during calmer conditions.

Operating sprinklers at lower pressure can reduce losses in the air and water blown off paddocks by keeping droplet sizes up. Using systems that place water close to the point where it is required, such as drop tubes on centre-pivots or travelling irrigators, will also reduce distortion and losses.

5.11 HOW TO HANDLE SOIL VARIATIONS

The likelihood of obtaining optimum production is greater on uniform soils than on soils that have large variations in water holding capacity. Variable soils create difficulties with matching irrigation applications to soil moisture deficits.

If irrigation applications are based on the smaller depletions of the lower water holding capacity soils, the parts of the farm with the high water holding capacity soils become wetter than needed, and water can be wasted. If the applications are based on the high water holding capacity soils, the moisture content in the low water holding capacity soils could drop below the stress point, and production losses will occur.

Unfortunately, irrigation systems that are able to precisely match irrigation applications to variable soil moisture deficits are extremely expensive. If possible, it is best to irrigate different soil types separately, but this may not be a realistic option on many farms.

Generally, the paddock is scheduled based on the low water holding capacity soils because the potential irrigation savings are lower than the potential yield losses. However, because evapotranspiration tends to be lower on the poorer soils and higher on the better soils, the amount of water to apply is based on the depletion on the high water holding capacity soils.

The rate at which water should be applied may also vary because of varying soil infiltration rates or areas with steep slopes. Either of these factors may change the application efficiency and alter the depth requirement. The irrigator should select the most representative situation in the paddock and irrigate to that.

5.12 IRRIGATING WITH LIMITED SYSTEM CAPACITY

When irrigation system capacity will not satisfy crop water requirements during the peak of the irrigation season, the period of the season where limitations will occur should be identified before the season starts, and a strategy developed to accommodate the limitation.

The situation is quite different to using the latest irrigation date strategy that is recommended for systems with adequate system capacity to maximise the use of rainfall.

If the irrigation is delayed to use rainfall effectively and to maximise water use efficiency, soils could dry out to below the stress point as the season develops because the system will not be capable of keeping up.

The irrigation manager must store as much water as possible in the soil by maintaining soil moisture levels up at field capacity at the beginning of the season, and holding them at that level for as long as possible. This requires looking forward to the maximum ET periods, i.e. mid-summer rather than just looking at the current irrigation cycle. It means starting irrigation early enough with a trigger level that returns the soil to field capacity.

If the practice of storing water in the soil is not able to prevent crop stress in mid summer, the response to stress of various crops should be considered, and subject to economic value, the crops with the highest sensitivity to stress should be irrigated first.

With many well-watered crops, the consequences of stressing the crop in mid-season could be more severe than uniformly stressing the crop throughout the season. Stress conditioning, and controlled deficit irrigation, that is deliberately stressing crops at various stages, can be planned at the start of the irrigation season.

The key point with irrigation under a limited system capacity is to develop an irrigation management plan at the beginning of the season, so that the plan can be implemented, and the best results possible obtained from the limited water.

5.13 WASTEWATER IRRIGATION

5.13.1 Nitrogen Loading

Nitrogen loading in the wastewater can place pressure on the environment due to nitrates leaching into groundwater or surface runoff discharging into waterways. If the wastewater application area is too small the soil will become overloaded and nitrogen may leach into groundwater.

Application of wastewater at rates that can be utilised by the pasture or crop pose less threat to groundwater or surface water. Application at higher rates will result in larger leaching losses and consequently higher nitrate concentrations in groundwater.

The following points regarding the leaching of nitrates following wastewater application to the land should be noted:

- Leaching losses can be high from soils ploughed, subject to wastewater application and then left fallow over an extended period;
- Leaching losses are generally low with a pasture cut for hay and/or silage; and
- With all crops, leaching loss depends on the application rate relative to plant requirement.

There is unlikely to be a need for nitrogen fertiliser to be applied to soils that receive wastewater.

5.13.2 Operational Guidelines

The following operational guidelines should be applied to areas irrigated with wastewater:

- The nitrogen loading rate (kg/ha/year) should not exceed that allowed for in the permit covering this activity.

- The maximum depth of any application should not exceed 50 percent of the water holding capacity of the soil.

- The wastewater application system to be managed so that ponding of wastewater does not occur.

- The wastewater application system to be managed so that no runoff into any surface water body or neighbouring property occurs.

- Most Regional Councils and Unitary Authorities have specific regulations regarding the distance of the irrigation of wastewater from any water race, river, stream, creek, lake, wetland or other surface water, as well as the distance to any well used for drinking water supply.

- The wastewater should be applied as evenly as possible over the area set aside for wastewater irrigation.

- Wastewater should be applied to short pasture, which is immediately after grazing.

- Allow at least a 7-day withholding period prior to grazing after applying wastewater.

- For hay and silage, wastewater should not be applied within 14 days prior to harvesting.

- For cropping land, wastewater should be worked into the topsoil before sowing or planting.

- Where freezing of the wastewater in the delivery lines can occur gravity drain the line after use.

Generally the highest odour emissions occur while the application of wastewater is taking place. The most practical way of reducing aerosoling effects is to use low pressure spray nozzles (i.e. 100 kPa to 300 kPa) with large orifices (i.e. between 8 mm and 16 mm).

The following management strategies should be followed to minimise odour nuisance and hygiene problems:

- Avoid spraying at night. Stable atmospheric conditions, which slow micro-organism die off and odour dispersion, usually occur at night or during calm mornings when temperature inversions exist. Further, more any faults in the system are unlikely to be detected at night and permanent system damage, soil overloading and subsequent accidental breaches of regulations may result.
- Avoid spraying at weekends, on public holidays and in the evenings when people are around.
- Check wind direction in relation to nearby dwellings before application. Spraying up wind of nearby dwellings should be avoided.
- The best conditions for application are those causing odours to disperse quickly, typically sunny windy days followed by cloudy windy nights. The worst weather

conditions for odour dispersion are typically high relative humidity and very light winds or clear still nights.
- Any odour complaints received are logged in a diary and all complaints are investigated and corrective action taken.

5.13.3 Nuisances and Odour

Wastewater must be applied to land in such a way that it does not cause a nuisance to the public or endanger human health.

The land application of wastewater should not:

- promote physical nuisances such as flies;
- generate odour nuisance; and
- create health risks and hygiene problems.

These problems can be overcome by the use of buffer zones and sensible application management.

Most Regional Councils and Unitary Authorities have specific regulations regarding the proximity of the land receiving wastewater to neighbouring properties, public roads, neighbouring dwellings and surface water.

5.14 ENERGY MANAGEMENT PRACTICES

Irrigators can limit the cost of energy by employing energy-saving practices into their irrigation management strategies.

5.14.1 Reducing Pumping Hours

Reducing pumping hours has an immediate effect on electricity use. This can be achieved by reducing the seasonal depths of irrigation applied, or by improving irrigation efficiency, and is possible without physically changing the irrigation system. Separating out the effects of irrigation efficiency and application depth is difficult. However, efficient irrigation scheduling can significantly reduce the amount of irrigation water pumped, and through that, energy use.

The biggest opportunity in New Zealand for reduced pumping is through better use of rainfall. Managing the irrigation system to use as much of the rainfall that occurs in a season as possible has direct benefits, because that water does not have to be pumped. Effective use of rainfall has been described in Section 5.9.

5.14.2 Improving Irrigation Efficiency

Improving application efficiency reduces the gross water applied and reduces energy use.

The net water used by the crop is climatically driven, and is independent of the irrigation system. The gross irrigation depth applied that is necessary to maintain plant growth depends on irrigation system type and the irrigation management practices used. However, except perhaps for systems that apply large fixed depths of water, irrigation efficiency depends more on management than on the irrigation system.

Irrigation efficiency changes during the irrigation season. For systems with limited system capacity, efficiencies may be lower at the beginning of the season because of the need to totally fill the soil profile. As the soils dry out as the season develops, irrigation efficiency increases, because the system does not have the capacity to fill the soil profile completely.

Poor irrigation efficiency depends primarily on four inter-related factors. These are: irrigation timing, which is a function of soil moistures before irrigation; the depth applied, which is a function of soil moistures after irrigation; application uniformity, which affects how much of the water will be lost to deep drainage; and application rate, which if excessive, causes poor uniformity because of surface redistribution.

Opportunities for improving irrigation efficiency are specific to each site. These can range from minor improvements to the irrigation system through to major equipment changes.

Simple changes to management such as adjusting application depths through nozzle size changes and covering the area more quickly (if equipment allows), may result in significant efficiency improvements. Close monitoring of irrigation applications through soil moisture measurement can result in significant reductions in water pumped. Proper maintenance of the system, for example by replacing worn sprinklers and nozzles, or blocked emitters, will improve efficiency.

Major changes, such as changing the type of irrigation, for example from flood irrigation to pressurised sprinkler irrigation, could result in significant improvements in irrigation efficiency. However, the benefits in terms of energy use may not be realised if the flood irrigation system was previously a gravity supply system that did not involve pumping.

5.14.2 Reducing Pump Pressure

There are a number of ways of reducing the pump duty required for an irrigation system, but most require large physical changes to the system.

Changing to low pressure spray nozzles will reduce energy consumption, but may not result in significant savings because of the high application rates that occur, causing surface redistribution and run-off. Whether reducing the operating pressure of sprinklers is worthwhile depends on what percentage of the total pump head the sprinkler requirement makes up. For deep well pumps, most of the energy is used to lift water to the surface, and modifying the system at the surface will change little percentage-wise.

Replacement of pressurised systems with surface systems will certainly save energy, but if more water has to be pumped to make up for lower efficiency, the benefits may not be significant.

5.14.4 Improving Pump Efficiency

An efficiently designed pumping plant is necessary to minimise energy required for pumping.

Different pump brands and types of pumps can have quite different efficiencies even though they are pumping the same amount of water. This efficiency depends on the design of the pump. Likewise, different motor brands have different efficiencies. The energy cost of running the system depends on both of these factors.

The key to an efficient pumping system is to select the best motor/pump combination at the design stage. If the better combination is more expensive, an economic evaluation should be made to determine if the possible savings in energy outweigh the additional capital cost.

Operating a pump at a flow at or beyond its maximum efficiency point will reduce the cost per cubic metre of water pumped.

As pumps wear, they become less efficient. Monitoring performance with pump tests will tell you whether or not loss of performance is significant enough to warrant repairs.

5.14.5 Electrical Load Management

Irrigators do not have much influence over electricity prices or the reliability of supply. There is a trend for some electricity supply companies to tailor tariffs to suit irrigation, or to offer load management options, but these are not yet common.

Where cheaper night rate electricity options are available, there is a temptation to design irrigation systems to only operate within those hours, even during peak irrigation periods. For a ten-hour night rate period, irrigation systems have to be designed with over twice the capacity as they do if the system is operated over the full day. This means bigger pipes, pumps and system components, and a much higher cost system.

Given that irrigation systems only need to operate at their peak capacity for part of the season, it is usually much cheaper overall to design systems to utilise the full day, operate at night whenever possible, and extend irrigation into day time rates when demand requires it.

6 Operating the Irrigation System

6.1 COMPLETING THE PRE-SEASON CHECKS

Before beginning any irrigation, pre-season checks should be carried out. These should include:

- Calibrating equipment. Check flow measuring equipment, soil moisture monitors, pump rating etc. to ensure the equipment is performing to specification;
- Application depth checks. Using a rain gauge or similar device, check the depths that the irrigation system is applying. This may need to be carried out a few times each season to establish how depths change with climatic conditions;
- Checking uniformity of application. While checking application depths, check the uniformity of application for the irrigation system;
- Recording baseline information such as paddock sizes, crops, and soil water holding capacities.

6.2 IMPLEMENTING THE PLAN

The irrigation strategy planned at the start of the season should then allow you to decide when and where to irrigate, and how much water to apply.

Operating the system is, in effect, carrying out the plan. It is the "DO" part of the plan-do-monitor-review process described in Section 1.2.

6.3 USING INDICATORS TO MONITOR PROGRESS

Monitoring progress towards meeting your goals and determining whether or not your irrigation strategy is performing to expectations requires you set performance targets and measure whether you are moving towards those targets.

The indicators recommended in LE Report No 2720/1 have been developed for this purpose.

The indicators have been divided into four groups for convenience, (economic, environmental, soil health, and social indicators) and are summarised in Tables A, B, C and D respectively. A summary of the information needed to be recorded, and the equipment needed to record the information is also given in the tables. The soil health indicator is an aggregation of a number of soil properties, and although it is an environmental indicator, it has been listed separately for clarity. All of the indicators are essentially seasonal indicators, but for some of them, daily information must be recorded to obtain the seasonal values.

Table A: Economic Indicators

Indicator	Task	Equipment/Information Needed
Annual net operating profit after tax ($).	Record profit from financial records.	Financial records/accounting system.
Profit per unit of water used ($/m^3).	Record profit and total seasonal water use.	Water use records. Financial records.
Production/unit of water used (tonnes of each crop produced per m^3 of water applied to that crop).	Record production of each crop and water applied to each crop in the season. (Refer to Note 1)	Daily water use records, seasonal production records.
Quantity produced/hectare for each crop (t/ha) (tonnes/ha for each type of crop).	Record production of each crop.	Production records.
Quality of produce (% at each grading level).	Record the different grades of crops produced.	Appropriate measure of quality (e.g. high/low grade product). Record sheet.
Annual energy used to operate irrigation system (kWh).	Record the amount of energy being used by the irrigation equipment from irrigation electricity meters.	Electricity meter readings for irrigation pumps.
Energy used per volume of water pumped (kWh/m^3).	Use annual energy use and total seasonal water use from above.	Electricity meter readings and water use records.
Labour units per irrigated area (hours per hectare).	Record time spent on irrigation annually.	Daily record sheets.

Note 1 - Flow measurements

Because it is important to measure the productivity per unit of water for each crop, the daily irrigation flows need to be proportioned between paddocks. If there is only one irrigator operating, the flows onto the farm can be calculated using water meters or electricity usage. However, if there are two or more irrigators operating from a single pump, the best way to obtain the volumes applied to each crop is from water meters on each irrigator. Otherwise, it is not easy to assign volumes to each crop, particularly if the irrigators are not identical or are run at different speeds.

A paddock is defined as an area containing the same crop, the same soil type and watered in the same irrigation setting.

Table B: Environmental Indicators

Indicator	Task	Equipment Needed
Resource consents obtained and complied with.	Record consent applications and outcomes.	
Daily volumes of irrigation water flow onto farm for each crop (m^3)	• Read water meters daily. • If using electricity meter for flow measurement, keep log of pump hours, and electricity meter readings. • For surface systems, keep log of hours system operates, and read level in weir/flume.	• Log of irrigation hours. • Weir/flume for surface systems. • Meters on pump headworks, or if more than one irrigator a meter on each irrigator.
• Daily percentage of water flowing onto farm that is stored in the root zone (%).	• Record daily rainfall, irrigation applied and soil moistures, and calculate the expected drainage. (Refer to Note 2) • For effluent irrigation, use sample quantities collected from lysimeters collected at the required frequency.	• Soil moisture measurement device or service. • Rain gauge. • Lysimeter for effluent irrigation.
• Daily visual assessment of the amount of surface water runoff.	• Record location, extent time and possible cause of any ponding.	• Daily records.
• Maximum water abstraction rate each season (m3/day).	• Identify day on which greatest amount of water was abstracted and record volume.	• Daily records.
• Lysimeter-based measurement of nitrogen leaching below the root zone (effluent irrigation only).	• Collect drainage water from lysimeters on a regular basis (dependent on required time interval), label and send to registered laboratory for analysis. Record results. (See Note 4)	• Lysimeter (s) placed in appropriate areas. • Sample bottles -sterile and labelled (check whether preservative is required for sample). • Record sheet for results.

Note 2 - Soil moisture measurements

- Most of the decisions relating to daily irrigation decisions require soil moisture to be measured in each paddock. For the purposes of irrigation management, two areas can be considered part of the same paddock if they contain the same crop and soil types, and are watered on the same day.

- There is some opportunity to reduce the number of soil moisture readings that are required to properly manage the whole farm. If two or more paddocks contain the same crop on the same soil type, then only one paddock needs to be monitored to determine how much water the crop is using. This water-use information can be used to determine soil moisture levels in the other paddocks. Furthermore, crop factors can be used to relate the water uptake by one crop to that of other crops on the same soil type.

Table C: Soil Health Indicator (water holding capacity, total organic nitrogen and carbon, pH, soil surface aggregates)

Indicator	Task (Refer to Note 3)	Equipment Needed
• Soil water holding capacity (maximum amount of water that the soil can hold which is available to plants measured in mm).	• Measure amount of water held in root zone. • Sampling a saturated, but free-draining soil and measuring the amount of water present (% by volume), either by conventional methods (laboratory analysis), or by direct soil moisture measurement. • Obtain data on wilting point for standard soil types.	• Conventional sampling equipment - Auger, depth measurement, sample bag. • Direct soil moisture measurement equipment. • Data on wilting point for standard soils.
• Total organic Carbon and Nitrogen (g/m^3).	• Collect soil samples from selected sampling areas at the same time each year in the approved manner label and send to laboratory for analysis.	• Plan showing sampling areas. • Auger for taking soil samples (75 mm depth is standard). • Labelled sample bags. • Record sheet for results.
• Soil pH	• Collect soil samples from selected sampling areas at the same time each year in the approved manner, label and send to laboratory for analysis.	• Sampling plan showing area. • Auger for taking soil samples (75 mm depth is standard). • Labelled sample bags. • Record sheet for results.
• Soil surface breakdown of aggregates.	• Visual assessment.	• Refer to Appendix III.

Note 3 - Soil monitoring

Soil monitoring should be undertaken in the same place at the same time each year. Samples should be collected from every different soil type on the farm, and areas growing different crops. Usually, a 'z' shaped path is walked through a paddock, with samples taken every 10 m or so. The samples are then mixed thoroughly, and a portion sent to a suitably registered laboratory for analysis.

Refer to Appendix III.

Note 4 - Water quality monitoring - Lysimeters (effluent irrigation only)

Samples taken for water quality analysis need to be collected carefully to eliminate chance of contamination by other sources. The sample bottles must be clean and sterile, and depending on the type of analysis required, may need preservative or chilling to stop the composition of the water changing on the way to the laboratory. Samples usually need to be sent to the laboratory as soon as possible after collection. Remember to label the samples carefully - place, date, time. Sampling for nitrate requires that the sample be kept at 4 °C, and is analysed within 48 hours.

Table D: Social Indicators

Indicator	Task	Equipment/Information Needed
Abatement notices.	Retain abatement notices, and record date, time and date of incident.	

6.3.1 Determining Baseline Indicators

Before the first irrigation season that the indicators are going to be used to monitor progress, it will be necessary to determine indicators to provide baseline values for comparison later. These baseline indicators may require information from the previous season in order to calculate them.

The information sheets given in Appendix I can be used to record these indicators.

6.3.2 Obtaining Daily Information

These are the indicators that require daily flows, drainage, surface ponding and for effluent irrigation, nitrogen leaching to be measured. Nitrogen leaching is based on lysimeter readings, and need not be measured daily.

Appendix II contains a form, which we suggest farmers fill in on a daily basis, so that these indicators can be calculated. The information required to do this is:

- dates;
- daily rainfall;
- soil moisture readings;
- irrigation depth applied (based on checks of application depth);
- hours of irrigation;
- notes on any obvious surface runoff or ponding;
- labour hours.

6.3.3 Determining End of Season Indicators

At the end of the season, the indicators listed on the information sheet in Appendix I should be recalculated so that they can be compared with the previous seasons values.

7 Reviewing the Seasons Irrigation

At the end of the irrigation season, a review should be carried out to determine the success or otherwise of the irrigation strategy used, and to get a measure of the overall performance of the irrigation system.

Assessing the effect of irrigation on production, profit, the environment and the community, needs to be carried out. Further to this, knowing what the water, energy and labour cost has been for the season will be helpful in planning the next season's irrigation.

The recommended indicators can be used to do this. The current indicators need to be compared to previous indicators to determine the direction of change. If indicators are moving in a positive direction, the changes implemented at the previous review have been effective. If the indicators are moving in a negative direction, the previous changes have had adverse effects on the system, and the reasons for the adverse effects must be identified before making the next change.

The following notes refer to some of the options available to farmers to assess the indicators and give suggestions for improvements.

7.1 RESOURCE CONSENT CONDITIONS

What is the relationship between the peak flow and the resource consent conditions? Are the weekly and seasonal volumes consistent with the conditions?

Relevant indicator

- Resource consents obtained and complied with.

You will need to check your daily records to determine volumes abstracted and compare them to the resource consent conditions.

If the actual abstractions are higher than allowed, the reasons should be identified and measures taken to comply with the consent. In particular, you should note whether it was a one-off event or a regular occurrence. Note that the reasons for the higher flows or volumes could be technical or managerial. It may have been due to a technical failure such as pipe leakage, or may have been a result of inefficient irrigation, or simply because the area and/or type of crop irrigated requires more water than the resource consent allows for.

If the peak abstraction was lower than allowed, then the resource consent has been complied with.

7.2 DAILY AND SEASONAL VOLUMES OF WATER USED

Is water use as expected? How does the seasonal volume used change over time? Are there any unexpected changes in flow rates when operating the system at different locations? Is the irrigation system applying the required depth? How efficient was your irrigation? What percentage of your total water supply was actually used by plants? Is the peak flow equal to the design capacity of the system? Are the flow rates or daily volumes consistent with the design capacity of the system.

These are some of the many questions you could ask relating to water use.

Relevant indicators

- daily volumes of irrigation water flowing onto the farm for each crop;
- daily percentage of water flowing onto farm that is stored in the root zone;
- daily visual assessment of the amount of surface runoff;
- maximum water abstraction rate each season.

If water use too low, then either it has been a very wet year, or the system is not performing to capacity, or crops are being underwatered. This could be caused by:

- worn pumps;
- blockages in the distribution system (e.g. clogged filters);
- problems with the water supply;
- problems with the soil moisture measuring equipment;
- wrong size nozzles on irrigation equipment;
- poor management.

Pumps, wells, filters and the water supply in particular should be checked. If necessary, replace or recalibrate soil moisture measuring equipment.

If the flow rates are variable, likely causes are:

- operating outside system specifications;
- unacceptable variation due to pipeline sizes (poor design);
- pump duty problems;
- unaccounted for changes in elevation;

Check that the system is being operated within the limits specified in the design. Also check pressure losses in the system. A hydraulic analysis may be required to do this. If poor pump performance is suspected, a pump test or hydraulic analysis is recommended. You may need to change the operation of the system, system components or flow rates if a design problem is identified.

If water use is too high, then you have probably been irrigating inefficiently. Either water was lost before it reached the soil, or water was lost as drainage.

To find out how much water is lost before it reaches the soil surface, your daily records should be checked. The amount lost should range from 0-20 percent of the total amount extracted, with the actual amount dependent on the type of irrigation system.

If losses are greater than this, likely causes are:

- leaks in the distribution system;
- surface ponding;
- wind-drift;

- watering areas outside of paddock area; or
- the system is applying higher irrigation depths than expected.

You should:

- fix any leaks;
- change the system application rate or depth to reduce surface ponding;
- adjust irrigation strategy for windy conditions;
- adjust irrigator positions to prevent overthrow; or
- change the sprinkler or irrigation settings to reduce the depths applied.

Check daily records to determine maximum daily volume abstracted. If the peak flow has reduced over the last season, you should identify the causes and rectify them. Possibilities are:

- pump wear;
- irrigation plant wear;
- water supply degeneration;
- well levels dropping;
- screen blockages;
- diversion problems; or
- channel deterioration.

7.3 DRAINAGE DEPTHS AND VOLUMES

How much water was lost to drainage through the root zone? Does the soil moisture reading taken below the root zone agree with the calculated drainage depth?

Relevant indicator

- Daily percentage of water flowing onto farm that is stored in the root zone.

Losses to drainage through the root zone should be examined to find out if there has been substantial drainage flow.

Based on the daily information, examine how much water applied to the soil (irrigation plus rainfall) was lost as drainage. For a good sprinkler system the amount lost should be less than 20 percent of the total amount applied during the season. For a border dyke system, up to 80 percent of the applied water could be lost on a seasonal basis.

Try to find out the cause of most of the drainage. Was it caused by rainfall or over-irrigation? Check the actual irrigation depths that each irrigator has applied

The likely causes of problems in this area are:

- an irrigation depth was applied that exceeded the depth of water the soil could absorb;
- excessive rainfall;
- uneven application depths (low uniformity);
- surface redistribution;

- design effects;
- component manufacture effects;
- irrigator is applying more than the design (or expected) depth.

Usually, better irrigation management can significantly reduce problems in this area. Check to make sure that your irrigation strategy takes into account the relevant factors described in the Planning Section.

7.4 SURFACE PONDING AND RUNOFF

Is any surface ponding evident?

Relevant indicators

- daily visual assessment of the amount of surface runoff;
- indicator of soil health (soil surface breakdown of aggregates).

If the daily records of visual assessments of surface ponding show that ponding or surface runoff has occurred frequently, likely causes are;

- a sealing layer has developed on the soil surface;
- insufficient crop cover;
- leaks in distribution system;
- topography of land is unsuitable for the irrigation method used;
- irrigation application rate or depth is too high.

If the problem is occurring on a newly planted crop, the surface runoff or damage to the soil surface may be reduced significantly or eliminated once the crop cover increases.

The impact of a sprinkler jet on the soil surface may be reduced by increasing pressure to obtain smaller droplet sizes, or changing the angle of contact for the jet.

If the problem is occurring on an established crop such as pasture, the design application rate may simply be too high for the soil type. The first thing to try is to reduce the application depth so that less water is applied more often. The higher infiltration rate that normally exists at the start of the irrigation may be enough to solve the problem. If the problem persists, it will be necessary to reduce the application rate of the system. A change of sprinkler type to increase the wetted coverage of the system may be an option. A reduction in pressure to reduce the application rate may be another. If these changes do not solve the problem, a different type of irrigation system may be required.

7.5 SOIL HEALTH

Has the general health of the soil changed?

Relevant indicators

- total organic carbon;
- nitrogen;
- soil pH;

- water holding capacity.

Refer to the report *Soil Quality Indicators for Sustainable Agriculture in New Zealand‡* for advice on these issues.

7.6 NITROGEN UNDER EFFLUENT IRRIGATION

Does the amount of nitrogen exceed resource consent conditions?

Relevant indicator

- Lysimeter-based measurement of nitrogen leaching below the root zone (effluent irrigation only).

The amount of nitrogen leached will be closely related to daily volumes of water infiltrating below the root zone.

If nitrogen amount is too high, likely causes are that daily drainage volumes are excessive or nitrogen loading is too high.

Refer to Section 7.3 for ways to change drainage flows.

7.7 PROFIT

Is farm profit as expected? Has expenditure on irrigation been higher or lower than expected? Has profit per unit of water used increased or decreased?

Relevant indicators

- annual net operating profit after tax ($);
- profit per unit of water used ($/m^3).

Annual net operating profit is influenced by a large number of factors. However, improved irrigation management should result in increasing profits due to irrigation in the long term. If it doesn't, then irrigation is not sustainable.

To obtain the net income attributable to irrigation, the capital and operating costs of the irrigation system should be subtracted from the income arising from increased yield. If the income has decreased from the previous year, you should try to find out whether the decrease is due to increased expenditure on irrigation, lower yields, or lower product prices. If it is due to lower yields, then perhaps your irrigation management has not been as good as in previous years. If it is due to increased expenditure, you should note whether it is a one-off cost, or a recurring cost, and if recurring, changes may be necessary to reduce this cost in future seasons.

‡ Cameron, KC; Conforth, IS; McLaren, RG; Beare, MH; Basher, LR; Metherell, AK and Kerr, LE (Eds)(1996): S*oil quality indicators for sustainable agriculture in New Zealand.* Proceedings of a Workshop. Lincoln Soil Quality Research Centre, Lincoln University.

7.8 PRODUCTION QUANTITY AND QUALITY

Are crop yields as high as expected and of appropriate quality? Has more or less water been used to produce the crop?

Relevant indicators

- production/unit of water used;
- quantity produced/hectare for each crop;
- quality of produce (% at each grading level).

If crop yields are higher than expected, then irrigation may have been more efficient than planned. This should be reflected in the water use indicators. Although many factors influence yield, the irrigation strategy has not been detrimental to production if yields have increased.

If crop yields are not as high as expected, or the quality of the crop has not been as high as expected, possible causes are:

- Moisture available to the crop was too low either throughout the season or at some critical time.
- Losses to drainage were too high and nutrient leaching occurred.
- The condition of the soil has deteriorated.

Increasing the system capacity of the irrigation system may be required. It could require changing your irrigation strategy, such as irrigating earlier in the season and avoiding stress periods. If losses to drainage are high, changing the irrigation strategy to apply less water more often may be needed.

Production per unit of water used can be interpreted in two ways.

The first assumes water use is from irrigation only, and will vary significantly from year to year according to rainfall. In wet years, irrigation water use will be low, and the indicator will be high. In dry years, the reverse will be true. Using the indicator in this way will give you an idea of trends in the long-term, but not in the short-term.

The second may assumes water use includes rainfall as well as irrigation, and gives you an idea of how well you have used rainfall and how efficiently you have irrigated. It is more useful to indicate progress in the short term.

7.9 ENERGY USE

Was energy use as predicted? Has the energy use per volume of water pumped changed significantly?

Relevant indicators

- annual energy used to operate irrigation system;
- energy used per volume of water pumped.

The amount of energy is directly related to pumped volumes and can be changed by adopting any measures outlined in Section 5.14.

7.10 LABOUR USE

Is the amount of time spent moving equipment reasonable, variable, decreasing or increasing? Was more time spent on irrigation than last season? How many hours of irrigation down time were there due to breakdowns?

The causes of downtime should be checked. Possible reasons are:
- Component failure due to unusual or excess conditions.
- Improper operation.
- Design faults.
- Failure due to normal ageing of system.
- Failure due to lack of maintenance.

If system breakdown has caused a significant increase in labour, replacement of equipment should be considered.

7.11 REGULATORY REQUIREMENTS

Have there been any abatement notices or resource consent renewals in the last season?

Relevant indicator

- Record of any abatement notices.

If there have been any abatement notices, the reasons for these should be identified, and steps taken to eliminate them in the future.

Appendix I

INFORMATION SHEET FOR RECORDING SEASONAL INDICATORS

(Note - Many of these values are calculated by cumulating values recorded on a daily information sheet detailed in Appendix II)
Details of how to measure and calculate the values are given in Table A in the text.

Environmental Indicators	1998	1999 Target	1999 Actual	2000 Target
Resource consents obtained and complied with. *If no renewal in current year, note renewal date*.				
Volumes of irrigation water flow onto farm (sum of daily values, m^3)				
Percentage of water flowing onto farm that is stored in the root zone (sum of daily values, %)				
Frequency of surface water runoff (number of days surface ponding evident from daily records)				
Maximum daily water abstraction rate each season (m^3/day)				
Lysimeter measurement of seasonal nitrogen leaching below the root zone (effluent irrigation only - summed from records during season, kg)				

Soil Health Indicator	1998	1999 Target	1999 Actual	2000 Target
Soil water holding capacity (mm)				
Total organic Carbon and Nitrogen				
Soil pH				
Soil surface breakdown of aggregates				

Economic Indicators	1998	1999 Target	1999 Actual	2000 Target
Annual net operating profit after tax (dollars)				
Profit per unit of water used ($\$/m^3$)				
Production/unit of water used (tonnes/m^3)				
Crop 1				
Crop 2				
Crop 3				
Quantity produced/hectare for each crop (tonne/ha)				
Crop 1				
Crop 2				
Crop 3				
Quality of produce (% at each grading level)				
Crop 1				
Crop 2				
Crop 3				
Annual energy used to operate irrigation system (kWh)				
Energy used per volume of water pumped (kWh/m^3)				
Labour units per irrigated area (hours/ha)				

Social Indicators	1998	1999 Target	1999 Actual	2000 Target
Abatement notices (number)				
Number of labour hours for irrigation of farm				

Appendix II

DAILY IRRIGATION INFORMATION SHEET
(Examples of some data entered)

Date : 4 February 1999					
(Shaded areas are seasonal information required to make daily calculations)	**Paddock 1**	**Paddock 2**	**Paddock 3**	**Paddock 4**	**TOTAL FARM**
Crop	Wheat	Barley	Barley	Barley	
Area	6 ha	12 ha	6 ha	6 ha	
Crop root depth [A]	500	700	700	700	
Soil water holding capacity (mm/m) [B]	150 mm	150 mm	150 mm	150 mm	
Total available water (field capacity) [C]	75 mm	105 mm	105 mm	105 mm	
Stress point (% of total available) [D]	50	50	50	50	
Readily available soil moisture [E]	37 mm	52 mm	52 mm	52 mm	
Date paddock last irrigated	20 Jan	16 Jan	26 Jan	15 Jan	
Soil moisture reading before irrigation [F]	45 mm	60 mm	80 mm	45 mm	
Soil moisture deficit [G]	30 mm	45 mm	25 mm	60 mm	
Depth of irrigation water applied [H]	40 mm	Nil	Nil	65 mm	
Drainage depth [I]	10 mm	Nil	Nil	5 mm	
Daily rainfall	10 mm				
Flow rate in pump or surface channel [J]	110 m^3/hr			180 m^3/hr	
Hours irrigation operating	23			23	
Daily volume of irrigation water abstracted [K]	2532 m^3	Nil	Nil	4140 m^3	6672 m^3
Volume of water applied to soil [L]	2400 m^3			3900 m^3	
Daily drainage volume [M]	600 m^3			600 m^3	1200 m^3
Moisture change below root zone? [N]	Yes	No	Yes	Yes	
Water lost before it reaches soil [O]	132 m^3			240 m^3	372 m^3
Surface ponding evident? Notes on location, climate and extent	Yes *at south end due to wind*				
Hours lost due to fixing irrigation equipment	Nil				
Labour hours	1.5			1.5	1.5
FOR EFFLUENT IRRIGATION ADD - *not always measured at daily frequency*					
Lysimeter area	0.2 m^2				
Effluent irrigation - lysimeter drainage volume			3 *l*		
Effluent irrigation - lysimeter nitrogen concentration (mg/l)			30 mg/*l*		
Effluent irrigation - nitrogen leached [P]			27 kg		27

Notes for filling in daily information sheet

A) The rooting depth of the crop at the above date. For non-permanent crops, it will not be realistic to change this daily, so estimates on a monthly basis are recommended.

B) The average soil water holding capacity in mm/metre over the expected maximum crop rooting depth.

C) Total available water in the root zone = $\frac{\text{water holding capacity} \times \text{root depth}}{1000}$ mm

D) The percentage of total available water at which crop growth begins to slow.

E) Readily available water = $\frac{\text{total available water} \times \text{stress point}}{100}$ mm

F) The soil moisture prior to irrigation determined from the soil moisture reading, which can be measured directly, or estimated using a water budget using ET figures and rainfall. If using soil moisture measuring equipment, the measured data may need to be converted to a depth in mm.

G) The depth of water that the soil can absorb = total available water less amount of water available prior to irrigation (C) – (F)

H) This is the depth of water that the irrigation system applies. Where practical, the application depths need to be periodically checked.

I) Drainage depth = water depth applied less depth of water that soil can absorb (H) – (G) (if negative then drainage depth = 0)

J) Pump flow rating or surface channel flow. Pump flow ratings may be constant over the season unless irrigation system uses a variable speed pump.

K) Volume of water abstracted (m^3) = hours of irrigation (hrs) × flow rate (m^3/hr)

Or if each irrigator is metered = volume recorded on meter

L) Volume applied to paddock/block (m^3) = 10 × application depth (mm) × area (hectares)

M) Daily drainage volume (m^3) = 10 × drainage depth (mm) × area (hectares)

N) Recorded if using soil moisture measurement below the root zone to detect saturation.

O) Water lost before it reaches the soil (m^3) = volume abstracted – volume reaching soil

P) Monitored using lysimeter.

Appendix III:

HOW TO ASSESS THE STRUCTURAL CONDITION OF YOUR SOIL

The structure condition of soil can be assessed by eye.

Carefully examine a spadeful of topsoil. After loosening by hand, compare the condition of the soil against the standard photographs with this booklet, or against a sample of pasture soil from an adjacent area.

The condition-score that is given is based on the size, shape and apparent porosity of the soil aggregate, the cohesion of the soil, the amount of dispersion or crusting of the soil surface, and the extent of root development.

Poorly structured light textured soil does not hold together and is at most risk of erosion.

Poorly structured medium and heavy textured soils consist of dense clods with few roots, smooth faces and occasional rusty orange spots. Although less prone to erosion this condition will reduce crop yield.

Soil should be examines at 5-10 locations in each paddock and an average score given on a scale of 1-10. A soil in good condition will have a high score (7-10) and a poor soil a low score (1-4).

Soil should have a condition score above 5 to ensure high crop yields and a low risk of erosion.

SCORE

1-2	Single grain structure, no cohesion of particles. Low in humus, very loose. **Or** Big dense clods, smooth faces. Roots only in cracks.
3-4	A few aggregates of low stability. Low cohesion. Loose. **Or** Big dense aggregates. Few porous aggregates.
5-6	Entire topsoil of large porous aggregates.
7-8	Plough layer almost entirely porous, stable crumb structure, occasional dense aggregates.
9-10	Entire plough layer consists of stable crumbs and few dense aggregates

Source: Canterbury Regional Council Information Pamphlet ("Controlling Wind Erosion on the Canterbury Plains")

Appendix IV:

GLOSSARY OF IRRIGATION TERMS

Available Soil Moisture

Also known as water holding capacity, available soil moisture is the difference in water content of the soil between field capacity and permanent wilting point. This is the soil water that is available for plants to use. By definition, it should be expressed as a percentage, or as a depth in millimetres per metre of soil, because the amount of water available to plants depends on this value and the root depths.

Capillary Water

The water held in the pore spaces of the soil by surface tension forces. It is available for plant growth.

Evapotranspiration (ET)

Evaporation is the transfer of water from liquid to water vapour. Direct evaporation normally occurs from the ground surface. Transpiration is the process by which plants remove water from the soil and release it to the atmosphere as water vapour.

Evapotranspiration is the sum of evaporation and transpiration, and is commonly regarded as the amount of water that a crop uses. It is governed primarily by climatic conditions.

Field Capacity (FC)

The amount of water held in the soil after excess water (gravitational water) has drained away, and normally occurs one or two days after heavy rainfall or irrigation. The determination of field capacity is extremely useful because it is one of the factors that allows you to calculate the amount of water available for plant use.

Field capacity corresponds to soil tensions of about 0.3 bars (0.08 bar for sands and up to 0.5 bar for clay soils).

Field capacity is also known as the full point of the soil.

Gravitational Water

Water that moves through the soil under the action of gravity and passes down to the water table.

Hygroscopic Water

Water held in the soil by molecular attraction and not capable of movement through the soil. It is not available for plant growth.

Oven Dry Soil

Soil that does not contain any water. All water has been removed.

Permanent Wilting Point (PWP)

The soil water content at which plants can no longer extract sufficient water from the soil to survive and grow. Even if the plants are irrigated at this stage, they will not recover.

Permanent wilting point corresponds to a soil tension of about 15 bar.

Potential Evapotranspiration (PET)

Potential evapotranspiration or potential consumptive use is the amount of water that a known or reference crop has the potential to use if it is growing at the maximum rate. In New Zealand, PET based on pasture is used as the reference crop, and all other crops are compared to this.

Readily Available Soil Moisture (RASM)
This is the amount of water held between field capacity and the stress point, and is commonly regarded as the maximum net amount of water that irrigation systems need to be able to apply.

Saturation
The water content of the soil when it is totally wet, i.e. it cannot absorb any more water.

Soil Tension
The surface tension forces holding water in the soil. It can be measured by tensiometers.

Stress Point

Also known as critical soil moisture content, this is the soil moisture content at which crop growth begins to slow down. This value depends on the soil, crop type and crop stage. A common guide is soil with a tension of 10 bar.

Trigger Level

This is the target soil moisture content that is used by the operator of the irrigation system to apply water. This soil moisture level is often the same as the stress point, but can be higher or lower, depending on the irrigation strategy used.

Wilting Point (WP)

The soil moisture content at which plants begin to wilt. Sometimes, hot dry days will cause plants to wilt during the daytime, but plants will recover at night. Temporary wilting is not uncommon. If irrigated, plants will fully recover, but during the wilting phase, growth will be slowed.