New Zealand Piped Irrigation System Performance Assessment Code of Practice

PART I: Conducting Energy Efficiency Assessments and Seasonal Irrigation Efficiency

Note: This is Part I of a series of nine (Parts A–I).

Part I: Contents

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The Code is presented as a series of booklets, each with a defined purpose.

Part A: An Introduction to Performance Assessment
Part A provides an overview of performance assessment, explains the broad philosophy behind assessment approaches taken throughout the Performance Assessment series, and contains specific formulae and reporting standards.

Part B: Compliance and Water Supply Checklists
Part B relates to all system types. It contains recommendations for checks to ensure compliance with regulations, rules and consent conditions, safe effective operation of water supply systems.

Parts C–H: System Performance Assessments
Parts C–H contain guidelines and recommendations for Operational Checks, System Calibrations and In-field Performance Assessments specific to a range of irrigation system types.

Part I: Conducting Energy Efficiency Assessments and Seasonal Irrigation Efficiency
(This booklet)

IrrigationNZ Technical Glossary
The Glossary and Calculations are common with the NZPIS Design Code of Practice.

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1. Conducting energy efficiency assessments

This section provides protocols for assessing energy efficiency in irrigation systems. They are intended to be used by irrigation managers and operators to check that energy use and loss are within expected boundaries.

The two largest areas of energy consumption in irrigation are pressurising and moving water by pumping, and losing energy through hydraulic friction. Therefore two related protocols are presented:

1.1 Assessing pump efficiency

1.2 Assessing delivery system efficiency

These protocols are suited to relatively simple systems. Complex multi-pump systems or ring main systems often require a detailed engineering analysis undertaken by experienced engineers with specialised software.

1.1 Assessing pump efficiency

The purpose of Pump Efficiency Test is to determine the energy efficiency of the motor and pump combination feeding the irrigation system.

The test is designed so irrigation managers can do measurement and calculations themselves. Supporting guidelines and worksheets are in the Appendices. Calculation software is available from IrrigationNZ. If findings are unexpected, or suggest low performance, consider getting professional advice.

A full or complex pump performance test must be performed by a trained service provider with appropriate testing equipment.

Why check pump efficiency?

Incorrectly sized or physically deteriorated pumps will waste energy and money. Efficient pumping minimises energy use and carbon emissions.

Pump and motor selection are important system design considerations. Incorrectly sized pumps and/or motors will not operate at their most efficient points. So they will waste energy.

The pump must provide adequate pressure and flow to ensure the system operates as designed. Low pressure is a common cause of poor irrigation uniformity which reduces overall system effectiveness and efficiency.

Excessive pressure affects performance and wastes energy. Pump selection will usually allow about 5% extra pressure capacity to allow for slippage with time. But excessively oversized pumps waste considerable amounts of energy. The presence of deliberate pressure reducing components or partially closed valves at the headworks indicates a need for careful assessment.

What will the testing show?

The main things the calibration test will show are:

- **Energy consumed**
  The kWh of electricity or diesel energy used to run the system; hourly and annually.
- **Pump efficiency**
  How much of the energy consumed (and paid for) is used to do useful 'work' driving the irrigation system.
- **Pump performance**
  How well the pump compares with typical values for that type and size of equipment.
- **Annual energy cost and savings**
  How much energy and money would be saved if the pump was operating at typical performance levels.

When should testing be done?

Complete the efficiency test when commissioning a new system and after any major changes to the pump or irrigation system.

The system operation should be 'typical' when the test is performed to ensure results are meaningful. If system flow or pressure changes when different parts of the irrigation system are operating, Delivery Efficiency will change.

Testing should be repeated as part of system checks at the start of every season. Compare with past results to identify slippage or failures.

What are the test's limitations?

The irrigation pump efficiency test will only provide information for the conditions measured, running at a given flow and pressure with a given depth to water. The energy use and efficiency will change if system pressure or flow changes or if the water table moves up or down.

The efficiency value determined is for the motor and pump combination. It is not easy to separate the individual performance of the motor or the pump. By looking at typical values, some indication is possible.

Results that show low efficiency indicate a need for detailed professional analysis.

ENERGY EFFICIENCY ASSESSMENT PROCESS

To assess pump efficiency, measured flow rates are combined with energy consumption information. This allows calculation of the energy efficiency of the motor and pump combination, operating as tested.

The process should be repeated if there are significantly different operating conditions, essentially varying system flow and/or required pressure.

NOTE:
Using this method, the intake pipe efficiency is included as part of the overall pump efficiency calculated.

NOTE:
In multiple pump systems, it can be possible to analyse each pump separately if pressures between pumps can be measured.

What needs to be done?

1. Gather information about the system
2. Calculate performance indicator values
3. Compare results with expected values
4. Determine if changes are justified.

GATHERING INFORMATION

The effective efficiency of a pump and motor combination can be estimated from power readings, flow rates and pressures. The information should be easy to obtain, and calculations needed are set out below.

NOTE:
Endeavour to record energy consumption and water use at the same time to ensure they are closely related.

NOTE:
Field recording sheets to assist are provided in the Appendices.

Equipment

Equipment needs are very basic and most should already be available on the property. A suggested list includes:

- 1 stop watch
- 1 pen or pencil
- 1 recording sheet
- 1 measuring jug (for fuel tank topping)
- pressure gauge(s) – rating depends on system pressures
- vacuum gauge(s) – rating depends on system pressures
- way to determine elevation difference between water level and pump outlet.

FIELD MEASUREMENTS

System measurements

1. Record motor details including power rating
2. Determine the mean energy cost of electricity and fuel
3. Determine the typical pump operating hours per year
4. Determine the change in elevation between the water surface (when pumping) and the centre of the pump outlet

NOTE:
This may require survey equipment and/or a method to measure water level in a bore or well

NOTE:
Information may be available from other sources such as design or construction information

Measure energy use

5. Determine the rate of energy use in kilowatts (kW)
   - *For electric pumps*
     – Run the system and record the duration
     – Record the power meter reading at start
     – Record the power meter reading at finish
     – Record any "multiplier" factor value.
   - *For fuel pumps*
     – Fill the tank to the lip if possible
     – Run the system and record the duration
     – Measure volume of fuel required to refill tank
     – Record volume consumed.

Measure water consumption

6. Determine system flow rate (m^3/h)

   NOTE: If a correctly calibrated water meter is fitted to the system, record and calculate water use.

   NOTE: If necessary:

   – Record the water meter reading (m^3) at start
   – Record any "multiplier" factor value
   – Run for a defined period consistent with electricity or fuel use recording
   – Record the duration
   – Record the water meter reading again (m^3) at finish
   – Record volume pumped.

   NOTE: If no meter is fitted, determine flow rate from field measurements by doing an irrigation calibration.

Measure system pressures

NOTE:
Ensure pressure gauges are in good condition

7. Measure water intake pressure (kPa)
8. Measure pump inlet pressure (kPa) (record a suction as negative pressure)
9. Measure the pump outlet pressure (kPa).

NOTE:
The water intake is usually not pressured. (Water depth above intakes or submerged pumps is included as the water surface level to the pump difference for Elevation Head.)

NOTE:
If there is positive head on the intake from a primary pump, subtract that pressure to get the increase in pressure generated by the pump being tested.

CALCULATE PERFORMANCE INDICATOR VALUES

Energy consumed

1. Calculate Pump Efficiency (%) = Work Done (kW) ÷ Total Power (kW) x 100
2. Calculate Total Power = Sum of all power used
3. Calculate Total Energy Cost = Sum of all energy costs.

NOTE:
Whether the pump runs on electricity or fuel or both, the kilowatt consumption must be calculated.

NOTE:
If there is more than one pump, add the energy use rates to get a total. Calculate energy use rate in the same units (kW) for both electric and diesel.

For electric pumps

Electricity meters show energy consumption in kilowatt hours (kWh) – the combination of energy use rate (kW) and time (hours).

4. Calculate Power (kW) = Energy Use Rate = Energy Used (kWh) ÷ Test Duration (h)
   - Energy Used (kWh) = Meter Difference (kWh) x Meter Multiplier Factor (fM)
   - Meter Difference = Meter reading (kWh) at end – Meter reading (kWh) at start
5. Calculate Annual Energy Use (kWh/year) = Use Rate x Annual Operating Time
6. Calculate Annual Energy Cost ($/year) = Annual Energy Use (kWh/year) x Energy Cost ($/kWh)

For fuel pumps

Convert fuel energy to kWh equivalent values.

7. Calculate Power (kW) = Energy Use Rate = Energy Used (kWh) ÷ Test Duration (h)
   - Energy Used (kWh) = Fuel Consumed (L) x Fuel Energy Factor (fFE)

   NOTE: Multiply fuel used by relevant factor from Table 1.1 (Lh x kWhL = kW)
8. Calculate Annual Energy Use (kWh/year) = Use Rate x Annual Operating Time
9. Calculate Annual Energy Cost ($/year) = Annual Fuel Use (L/year) x Fuel Cost ($/L)
   - Annual Fuel Use (L/year) = Fuel Use Rate (L) x Annual Operating Time
   - Fuel Use Rate (L/h) = Fuel Consumed (L) ÷ Test Duration (h)

Work done

10. Calculate Work Done (kW) = Total Dynamic Head (kPa) x Water Flow Rate (m^3/h)
    - Total Dynamic Head (kPa) = Elevation Head + Pressure Head + Inlet Friction Head
    - Elevation Head (kPa) = Elevation Change (m) x Specific Gravity (~ 9.8)
    - Pressure Head (kPa) = Pump Outlet Pressure (kPa) – System Intake Pressure (kPa)
    - Inlet-side Friction Head (kPa) = Inlet-side Pressure Loss

NOTE:
Inlet-side Pressure Loss may be determined using the Delivery Efficiency Assessment protocols.

NOTE:
Elevation head refers to the lift from the source water level to the pump discharge. It is the lift from the actual water level when the pump is running (drawn down) to the centre of the pump outlet.

NOTE:
Elevation head is usually positive, but if the water level is higher than the pump (e.g. a dam) the elevation change is recorded as a negative value.

NOTE:
Specific Gravity (SG ~ 9.8) accounts for the force of gravity.

NOTE:
The pump is working to overcome friction in the intake side of the headworks. To account for this, add the friction in the intake pipe. This can be determined using the Delivery System Efficiency protocols.

COMPARE RESULTS WITH EXPECTED VALUES

Relative pump efficiency

1. Calculate Relative Performance % = Calculated Pump Efficiency ÷ Reasonable Efficiency x 100
2. Calculate Potential Savings ($/year) = Annual Cost – Reasonable Cost
   - Reasonable Cost ($/year) = Annual Cost x Relative Performance ÷ 100

NOTE:
Pump efficiency shows how much of the energy consumed does useful work. It is usually given as a percentage.

NOTE:
Select a Reasonable Efficiency value for the test system from Table 1.1 and compare it with the calculated efficiency for the actual pumping plant. The relative performance is usually given as a percentage.

NOTE:
The cost of energy for a pumping plant with 48.6% efficiency is 44% more than a typical plant running at 70% efficiency.

NOTE:
Table 1.1 gives guidelines for expected efficiencies, based on motor size and assuming the pump is matched appropriately to the motor.

Table 1.1 Typical electric motor and pumping plant efficiencies by motor size

Electric motor kW	Efficiency % of full load motor	Efficiency % of correctly matched pump	Overall efficiency % pump & motor
2 – 4	80 – 86	55 – 65	44 – 56
5 – 7.5	85 – 89	60 – 70	51 – 62
10 – 22	86 – 90	65 – 75	56 – 68
30 – 45	88 – 92	70 – 80	62 – 74
> 55	90 – 93	75 – 85	68 – 79

Source: North Carolina Cooperative Extension Service, Publication Number: AG 452-6

Notes to Table 1.1

Pump-type variations

1. Values shown are typical for centrifugal pumps.
   NOTE: < 55 kW submersible pumps range 3–5% higher and turbine pumps range 5–10% higher.
   NOTE: > 55 kW centrifugal pumps may approach efficiencies of 88%, whereas large submersible and turbine pump efficiencies peak at about 90%.
2. Overall Pump Efficiency ranges are obtained by multiplying the Full Load Motor Efficiency range by the Matched Pump Efficiency range e.g. 80% x 55% = 44% (on a calculator 0.80 x 0.55 = 0.44)

Converting values for typical fossil fuels to usable energy values:

3. New Zealand Diesel contains 10.4 kWh/L but only about 3.5 – 4.0 kWh/L of useful energy are generated
4. New Zealand 91 Petrol contains 9.69 kWh/L but only about 2.5 – 2.8 kWh/L of useful energy is generated.

NOTE:
The usable energy values for diesel and petrol above are already adjusted for engine efficiency.

If using them as 'Power Conversion' factors, use values from the Matched Pump Efficiency column rather than the Overall Pump Efficiency column as the 'Typical' Pumping Plant Efficiency.

DETERMINE IF CHANGES ARE JUSTIFIED

Cost benefit

1. Determine costs of potential system change options
   - Larger intake pipes
   - Replacement pump/motor.
2. Estimate proportion of Potential Savings from each change option
3. Compare Potential Savings ($/year) with costs of change options.

NOTES:

- The pressure at the nozzle (the end nozzle if there is more than one) gives best guidance to adequacy of system pressure. Generating more pressure than required is wasteful and costly.
- Using an oversized pump will result in higher operating costs. New pumps may have spare capacity to allow for wear. However, if the system pressure is more than 5% over the sprinkler operating requirement, or if partially closed gate valves or pressure regulators are installed to 'burn-off' pressure, it is likely energy and money are being wasted.
- It is usually more economical in the long term to select the most efficient pump, even if it requires higher initial outlay. Replacing incorrectly sized motors or pumps can often have a quick payback.
- The efficiencies of the pump itself and the motor are combined for overall efficiency. For example, a 90% efficient motor on a 70% efficient pump is only 63% efficient overall (0.9 x 0.7 = 0.63).
- Check manufacturer's data sheets to determine the expected efficiency of the pump-motor combination. They should be selected to operate at or near their maximum efficiency points as much as possible.

Why does efficiency change?

There are two basic reasons for a pump being inefficient:

1. It has physically deteriorated
2. It is not suitable for the required operating conditions (i.e. required flow and pressure).

NOTES:

- Most irrigation systems are powered by electric motors or internal combustion engines, sometimes both. In general, electric motors are more energy efficient than diesel engines, which are usually more efficient than petrol engines.
- Differences in potential efficiencies between standard electric motors are generally small (1 5%), but as the motor is at the start of the drive train the savings achieved by an efficient motor and motor operating at its best efficiency point can be substantial.
- Changing flow or pressure requirements will change the pump operating point, and can move from its optimum to a less efficient performance.
- If pump loads fluctuate widely or if pumps are often run at partial loads, adding a variable speed drive may be cost effective since it closely matches output to actual demand. An alternative is to use multiple pumps turning on or off to optimise to different operating conditions.

1.2 Assessing delivery system efficiency

The purpose of this test is to determine the energy efficiency of the headworks and pipelines feeding the irrigation system. See also the guidelines for assessing the efficiency of the pumping system.

The test is designed so irrigation managers can do measurement and calculations themselves. Supporting guidelines and worksheets are in the Appendices. Calculation software is available from IrrigationNZ. If findings are unexpected, or suggest low performance, consider getting professional advice.

Why check delivery system efficiency?

Incorrectly sized or physically deteriorated components can waste energy and money. Energy efficient irrigation minimises energy use and carbon emissions. A good system saves money and the environment.

Pipe and component selection are important system design considerations. Selecting smaller options may reduce up front capital cost, but increases ongoing energy costs as bigger pumps are required. The correct selections optimise the necessary trade-offs.

A separate protocol deals with pumping system efficiency. The two should be used together.

What will the testing show?

The test will show water velocities in and energy losses from the irrigation system. These are described using 'performance indicators' which apply regardless of system type:

- **Headworks efficiency**
  How much of the energy consumed (and paid for) is lost at the headworks
- **Hydraulic (mainline) velocity and efficiency**
  How fast water is moving along the pipeline and the amount of friction loss
- **Suction line lift and velocity**
  The maximum suction and speed in the intake pipeline; important for safe pump operation
- **Annual energy cost and savings**
  How much energy and money would be saved if the delivery system was operating at typical performance levels.

When should testing be done?

Complete the efficiency test when commissioning a new system and after any major changes to the pumping or irrigation systems. It should also be repeated as part of annual maintenance.

The system operation should be 'typical' when the test is performed to ensure results are meaningful. If system flow or pressure changes when different parts of the irrigation system are operating, Delivery Efficiency will change.

Testing should be repeated as part of system checks at the start of every season. Compare with past results to identify slippage or failures.

What are the test's limitations?

The irrigation delivery system efficiency test will only provide information for the conditions measured. The energy use and efficiency will change if system flow changes.

The more accurate your input values, the more accurate your results. Take care reading pressure and determining elevation changes. Use good equipment in good order.

If pressure and suction gauges are not already in place, it may take a little setting up the first time this testing is done. Next time, the equipment will already be in place.

The efficiency value determined is based on guidelines in the New Zealand Piped Irrigation Systems Standards.

Get professional help if testing shows unexpected results.

ENERGY EFFICIENCY ASSESSMENT PROCESS

The Delivery System Efficiency Test is based on measurements collected on farm. Key information is pressure, elevation and flow rate so a process to accurately determine these at critical system points is required.

Combining flow, pressure and elevation allows calculation of the energy losses from friction as water flows through the system, operating under the conditions when tested.

Significant changes to flow rate will change the outcomes. If different irrigators, combinations of irrigators or permanent irrigation systems with blocks of significantly different sizes are used, the process should be repeated for each different combination.

What needs to be done?

1. Gather information about the system
2. Calculate performance indicator values
3. Compare results with expected values
4. Determine if changes are justified.

GATHERING INFORMATION

The efficiency of your delivery system can be estimated from flow rates, pressures and elevation changes. The information should be easy to obtain, and calculations needed are set out below.

NOTE:
Endeavour to record energy consumption and water use at the same time to ensure they are closely related.

NOTE:
Field recording sheets to assist are provided in the Appendices

Equipment required

- Stop watch
- Pen or pencil
- Recording sheet
- pressure gauge(s)
  - rating depends on system pressures
- vacuum gauge(s)
  - rating depends on system pressures
- way to determine elevation difference between:
  - water level and pump outlet
  - pump outlet and mainline entry
  - mainline entry and mainline exit

FIELD MEASUREMENTS

1. Record motor details including power rating
2. Determine the mean energy cost of electricity and fuel
3. Determine the typical pump operating hours per year
4. Determine the change in elevation between the water surface (when pumping) and the centre of the pump outlet

NOTE:
This may require survey equipment and/or a method to measure water level in a bore or well

NOTE:
Information may be available from other sources such as design or construction information

Measure energy use

5. Determine the rate of energy use in kilowatts (kW).

NOTE:
Refer to Assessing Pump Efficiency for process to determine Energy Use

Measure water consumption

6. Determine System Flow Rate (m^3/h)

   NOTE: Refer to Assessing Pump Efficiency for process to determine System Flow Rate

7. Determine the typical pump operating hours per year

Measure system elevations

8. Measure Water Intake elevation (kPa)
9. Measure Pump (Outlet) elevation (kPa)
10. Measure the Mainline Entry elevation (kPa)
11. Measure the Mainline Exit elevation (kPa)

NOTE:
This may require survey equipment and/or a method to measure water level in a bore or well

NOTE:
Information may be available from other sources such as design or construction information

NOTE:
Elevation accuracy is important! Work to the nearest tenth of a metre. Remember: 0.1m is about 1kPa. You can use actual elevations above sea level, or assume the pump shed floor 100.0m and determine all other elevations relative to that.

NOTE:
Water Intake elevation is the surface level of the water, NOT the position of the actual intake itself which must be under water. The level in a well may drop when the system is running.

SYSTEM MEASUREMENTS

Measure system pressures

NOTE:
Ensure pressure gauges are in good condition

12. Measure Water Intake pressure (kPa)
13. Measure Pump Inlet pressure (kPa) (record a suction as negative pressure)
14. Measure the Pump Outlet pressure (kPa)
15. Measure the Headworks Exit pressure (kPa)
16. Measure the Mainline Entry pressure (kPa)
17. Measure the Mainline Exit pressure (kPa)

NOTE:
Intake pressure is 0kPa unless there is a pre-pump or community pipe providing pressure. The water intake is usually not pressured. (Water depth above intakes or submerged pumps is accounted for in Elevation Head calculations.)

NOTE:
A vacuum gauge fitted at the pump inlet is needed to accurately determine intake side losses.

NOTE:
With no inlet suction gauge, only the headworks efficiency from the pump outlet can be calculated. (When the pump efficiency test is completed, the intake efficiency will be included as part of the overall pumping plant efficiency calculated.)

NOTE:
If there is positive head on the intake from a primary pump, subtract that pressure to get the increase in pressure generated by the pump being tested.

NOTE:
Mainline entry is the point where the headworks stop. It will be after control valves, filters, meters and injection points etc. It is the same as the Headworks Exit.

NOTE:
Mainline exit may be a block offtake or hydrant, or in the case of a centre pivot, the entry to the irrigator itself. In systems with multiple offtakes or hydrants, the first offtake may be considered, or each may be assessed.

Measure system dimensions

18. Measure Mainline length (m)
19. Determine Intake Pipe internal diameter (mm)
20. Determine Mainline internal diameter (mm).

NOTE:
The internal pipe diameter must be accurate and in most cases is not the ‘nominal diameter’ of the pipe. Either measure a sample or check with the supplier to confirm the right value. Small diameter errors cause big velocity errors.

CALCULATE PERFORMANCE INDICATOR VALUES

Headworks efficiency

Headworks efficiency is a measure of the hydraulic performance of the intake structure, pump and headworks (excluding pump pressure and elevation differences). It considers pressure loss in the system between the water take point and the mainline entry.

NOTE:
Pressure in the system is the result of pump input and pipeline friction losses, and changes in elevation.

NOTE:
Elevation effects are discounted to focus on the efficiency of pipes and components.

NOTE:
Use consistent measurement units:

- measure pressures in kPa
- Convert elevations from metres to kPa (multiply by specific gravity).

1. Calculate Headworks Efficiency (%) = (Residual Pressure Head ÷ Total Pressure Head) x 100
   - Residual Pressure Head (kPa) = Total Pressure Head – Total Friction Headloss
   - Total Pressure Head (kPa) = Inlet Side Pressure Head + Outlet Side Pressure Head
   - Total Friction Headloss (kPa) = Inlet Side Friction Loss + Outlet Side Friction Loss

Inlet side friction headloss

2. Calculate Friction Headloss (kPa) = Change in Pressure Head – Change in Elevation Head
   - Change in Pressure Head (kPa) = Pump Outlet Pressure – System Intake Pressure
   - Change in Elevation Head (kPa) = Elevation Change (m) x Specific Gravity
   - Elevation Change (m) = Pump elevation – System Intake elevation

NOTE:
Elevation head refers to the lift from the source water level to the pump discharge. It is the lift from the actual water level when the pump is running (drawn down) to the centre of the pump outlet.

NOTE:
Elevation head is usually positive, but if the water level is higher than the pump (e.g. a dam) the elevation change is recorded as a negative value.

NOTE:
Specific Gravity (SG ~ 9.8) accounts for the force of gravity.

Intake pipe velocity

3. Calculate Intake Pipe Velocity (m/s) = (System Flow Rate (m^3/h) ÷ 3,600) ÷ Pipe Section Area (m^2)
   - Pipe Section Area (m^2) = Pipe Internal Diameter (mm) ÷ 2,000)^2 x Pi

Outlet side efficiency

4. Calculate Friction Headloss (kPa) = Change in Pressure Head – Change in Elevation Head
   - Change in Pressure Head (kPa) = Mainline Entry pressure – Pump Outlet Pressure
   - Change in Elevation Head (kPa) = Elevation Change (m) x Specific Gravity
   - Elevation Change (m) = Mainline Entry elevation – Pump elevation

Hydraulic (mainline) efficiency

Hydraulic efficiency refers to the proportion of energy lost carrying water from the headworks to the entry to the 'irrigator' itself. The 'irrigator' might be a traveller, a pivot or a block of micro-irrigation. Hydraulic efficiency is an assessment of mainline performance. It can be determined from pressure readings and knowledge of elevation changes.

5. Calculate Mainline Friction Headloss (kPa) = Change in Pressure Head – Change in Elevation Head
   - Change in Pressure Head (kPa) = Mainline Entry Pressure – Mainline Exit pressure
   - Change in Elevation Head (kPa) = Elevation Change (m) x Specific Gravity
   - Elevation Change (m) = Mainline Exit elevation – Mainline Entry elevation

Mainline pipe velocity

6. Calculate Mainline Pipe Velocity (m/s) = (System Flow Rate (m^3/h) ÷ 3,600) ÷ Pipe Section Area (m^2)
   - Pipe Section Area (m^2) = (Pipe Internal Diameter (mm) ÷ 2,000)^2 x Pi

COMPARE RESULTS WITH EXPECTED VALUES

The maximum lift, including elevation gain and friction losses, must not exceed the practical limits for pumps. High water velocities or high pressure losses through suction lines can create major problems including cavitation and complete failure of centrifugal pumps.

Headworks efficiency

1. Calculate Excess Headworks Headloss
   Guideline:
   - Basic headworks including water meter, clean filters and gate valves, but excluding pressure control valves
   - Acceptable friction headloss < 30kPa.

NOTE:
Unclean filters may cause extra 10–50+ kPa headloss

NOTE:
Query the use of headworks pressure regulators. They are designed to burn off excess pressure. Unless you have changing conditions and need to protect your system, regulators are probably wasteful.

Intake side/suction line

2. Calculate Excess Intake Pipe Velocity (m/s) = Intake Pipe Velocity – Acceptable Intake Pipe Velocity

   NOTE:
   Excess velocity is the difference between the recommended maximum value and test results.
   A positive answer means excess velocity.

   Guideline:
   - Acceptable Intake Suction < 60kPa
   - Acceptable Intake Pipe Velocity < 1.5m/s (where pipe sizes are not determined by pressure variation or velocity requirements).

Excess energy cost

3. Calculate Annual Energy Loss Cost ($ p.a.) = Annual Energy Cost x Excess Friction Ratio
   - Annual Energy Cost [from Pump Efficiency Test Protocol)
   - Excess Friction Ratio = Excess Headworks Friction Loss ÷ Total Pressure Head
   - Excess Headworks Friction Loss (kPa) = Total Friction Headloss – 30

Hydraulic (mainline) efficiency

1. Calculate Excess Mainline Friction (kPa) = Mainline Friction Headloss – Acceptable Mainline friction loss
   - *Guideline:*
     Acceptable Mainline friction loss* < 100kPa
     *unless there is need to burn off pressure, such as in gravity supplied systems.
2. Calculate Excess Mainline Friction (kPa/100m) = Mainline Friction Loss – Acceptable Mainline friction loss
   - Mainline Friction Loss (kPa/100m) = Friction Headloss ÷ Mainline Length (m) x 100
   - *Guideline:*
     Acceptable Mainline friction loss*
     4–12 kPa/100m pipe
     *unless there is need to burn off pressure, such as in gravity supplied systems.
3. Calculate Excess Mainline Pipe Velocity (m/s) = Mainline Velocity – Standard Max Velocity

   NOTE:
   Excess velocity is the difference between the recommended maximum value and test results. A positive answer means excess velocity.

   NOTE:
   Higher speeds cause higher friction losses and increase the risk of damage through surges and water hammer. In high sediment conditions, minimum velocities may be needed to avoid blockages.

   NOTE:
   Large diameter pipes subject to uncontrolled starting and stopping are particularly sensitive. *The New Zealand Piped Irrigation System Code of Practice for Irrigation Design* recommends maximum water velocities:

Table 1.2

	Condition / location	Max velocity
< 150mm diameter pipe	open end, controlled start and stop	< 3.0m/s
	uncontrolled start and stop	< 1.5m/s
> 150mm diameter pipe	open end, controlled start and stop	< 2.0m/s
	uncontrolled start and stop	< 1.0m/s

DETERMINE IF CHANGES ARE JUSTIFIED

Cost benefit

1. Determine costs of potential system change options
   - Larger pipes
   - Larger headworks components.
2. Estimate proportion of Potential Savings from each change option
3. Compare potential savings ($/year) with costs of change options.

Why does efficiency change?

There are two basic reasons why a system is inefficient:

- it has physically deteriorated, and/or
- it is not suitable for the required operating conditions (i.e. required flow).

If the losses are higher than expected, assess the cost of efficiency improvement. In some cases, relatively minor changes can give considerable on-going energy savings.

2. Assessment of seasonal irrigation efficiency

This section outlines procedures for estimating measures of seasonal irrigation efficiency (SIE).

The indicators estimate the effectiveness and efficiency of irrigation scheduling on a seasonal basis. They are calculated using soil moisture budgets; tracing inputs and outputs from a conceptual reservoir of some set size.

The schedule identifies varying levels of analysis ranging from very simplistic to highly detailed. The simplest is a quick estimate of Seasonal Irrigation Efficiency based on comparing total seasonal irrigation and rainfall with total estimated seasonal evapotranspiration.

A more detailed process is recommended where information is available. Therefore the schedule outlines a process for more detailed analysis, requiring knowledge of soil water properties, seasonal weather, potential crop water use, and irrigation system performance and management.

DETERMINE SEASONAL EFFICIENCY

1. Process questionnaire responses to assess the adequacy and efficiency of irrigations for the preceding season
2. Estimate yield losses and values resulting from inadequate irrigation.

Purpose

This schedule presents procedures for estimating measures of seasonal irrigation efficiency (SIE). A wide range of efficiency measures may be used, depending on scale, timeframe and issues under consideration. Commonly used indicators include irrigation efficiency, irrigation adequacy and drainage.

Seasonal irrigation efficiency overview

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

The simplest indicator of Seasonal Irrigation Efficiency compares total seasonal irrigation and rainfall with total estimated seasonal evapotranspiration. A more detailed process is recommended where information is available.

This schedule outlines a process for more detailed analysis, requiring knowledge of soil water properties, seasonal weather, potential crop water use, and irrigation system performance and management.

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

SEASONAL APPLICATION EFFICIENCY

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

Beneficial uses include meeting evapotranspiration requirements, frost protection and salinity management. The prime consideration is crop evapotranspiration need. Frost protection is not included in these calculations.

The main indicator calculated is Seasonal Application Efficiency (SAE), the ratio of crop water use to applied irrigation, net of changes in soil moisture storage.

SEASONAL IRRIGATION ADEQUACY

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

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

Deep percolation (often referred to as drainage) resulting from irrigation (SDP_i), quantifies the amount of water that is lost to groundwater through non-uniformity or improper scheduling.

OTHER EFFICIENCY INDICATORS

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

Sources of information

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

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

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

WATER USE

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

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

WATER INPUTS

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

SOIL WATER HOLDING CAPACITY

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

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

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

Determination of input data

ACCURACY OF INPUT DATA AND RESULTS

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

SOIL MOISTURE CHARACTERISTICS

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

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

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

ESTIMATING CROP WATER REQUIREMENT

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

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

The crop water requirement calculated is described as crop-adjusted evapotranspiration (ET_{crop})

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

SYSTEM PERFORMANCE (DU_{LQ})

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

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

ROOT AREA WETTED

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

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

BENEFICIAL WATER REQUIREMENTS

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

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

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

CROP VALUE

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

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

Analysis detail

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

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

TIME PERIOD

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

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

SPATIAL VARIATION

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

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

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

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

SIMPLE ANALYSES

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

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

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

DETAILED ANALYSIS

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

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

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

Efficiency calculations

SEASONAL APPLICATION EFFICIENCY

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

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

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

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

EVENT IRRIGATION ADEQUACY

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

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

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

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

SEASONAL IRRIGATION ADEQUACY

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

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

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

POTENTIAL SOIL MOISTURE DEFICIT

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

SEASONAL POTENTIAL SOIL MOISTURE DEFICIT

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

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

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

SEASONAL DEEP PERCOLATION (SDP)

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

SEASONAL IRRIGATION DEEP PERCOLATION

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

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

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

DROUGHT INDUCED YIELD LOSS

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

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

VALUE OF LOST YIELD

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

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

VALUE OF WASTED WATER

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

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

VALUE OF WASTED ENERGY

The value of energy unnecessarily consumed is calculated from 'wasted' water, volumetric energy consumption and system efficiency factors. This integrates all energy losses, including those from poor headworks and mainline design.

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

IRRIGATION REQUIREMENT

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

Appendices

PART I: Conducting Energy Efficiency Assessments and Seasonal Irrigation Efficiency

Delivery system efficiency guidelines

What is the test about?

The purpose of this test is to determine the energy efficiency of the headworks and pipelines feeding the irrigation system. See also the guidelines for assessing the efficiency of the pumping system.

The test is designed so irrigation managers can do testing and calculations themselves. As well as this guideline, a worksheet is available to assist. If findings are unexpected, or suggest low performance, consider getting professional advice.

Why check delivery system performance?

Profitability – Incorrectly sized or physically deteriorated components can waste energy and money. A good system saves money!

Sustainability – energy efficient irrigation minimises energy use and carbon emissions. A good system saves the environment!

Pipe and component selection are important system design considerations. Selecting smaller options may reduce up front capital cost, but increases ongoing energy costs as bigger pumps are required. The correct selections optimise the necessary trade-offs.

A separate guideline deals with pumping system efficiency. The two guides should be used together.

What is involved?

The delivery system efficiency test is based on measurements collected on farm. Key information is pressure, elevation and flow rate so you need some way of accurately determining these at critical system points.

Combining flow, pressure and elevation allows calculation of the energy losses from friction as water flows through the system, operating under the conditions when tested.

Significant changes to flow rate will change the outcomes. If you use different irrigators, combinations of irrigators or have permanent irrigation systems with blocks of significantly different sizes, the process should be repeated for each different combination.

What needs to be done?

1. Gather information about the system
2. Record the data on the worksheet
3. Work out answers using the worksheet calculations
4. Compare your results with target values.

When should testing be done?

Complete the efficiency test when commissioning a new system and after any major changes to the pumping or irrigation systems. It should also be repeated as part of annual maintenance.

Make sure the system operation is 'typical' when you test, so your results are meaningful.

What will the testing show?

The test will show water velocities in and energy losses from the irrigation system. These are described using 'performance indicators' which apply regardless of system type:

- **Headworks efficiency**
  How much of the energy consumed (and paid for) is lost at the headworks.
- **Hydraulic (mainline) velocity and efficiency**
  How fast water is moving along the pipeline and the amount of friction loss.
- **Suction line lift and velocity**
  The maximum suction and speed in the intake pipeline; important for safe pump operation.
- **Annual energy cost and savings**
  How much energy and money would be saved if the delivery system was operating at typical performance levels.

What are the test's limitations?

The delivery system efficiency test will only provide information for the conditions measured. The energy use and efficiency will change if system flow changes.

The more accurate your input values, the more accurate your results. Take care reading pressure and determining elevation changes. Use good equipment in good order.

If you don't already have pressure and suction gauges in place, it may take a little setting up the first time you do this testing. Next time, your equipment will already be in place.

The efficiency value determined is based on guidelines in the *Irrigation New Zealand Code of Practice for Irrigation Design*.

Get professional help if testing shows unexpected results.

What is it and what's acceptable?

HEADWORKS EFFICIENCY

Headworks efficiency is a measure of the hydraulic performance of the intake structure, pump and headworks (excluding pump pressure and elevation differences). It considers pressure loss in the system between the water take point and the mainline entry.

Headworks efficiency can be determined from pressure readings and knowledge of elevation changes. We need consistent measurement units; in this guideline pressures are measured in kPa. Elevations are converted from metres to kPa.

Guideline – For a basic headworks including water meter, clean filters and gate valves, but excluding pressure control valves

- Maximum friction headloss < 30kPa

Unclean filters may cause extra 10–50+ kPa headloss

Query the use of headworks pressure regulators. They are designed to burn off excess pressure. Unless you have changing conditions and need to protect your system, regulators are probably wasteful.

INTAKE SIDE / SUCTION LINE

A suction pressure gauge fitted at the pump inlet is needed to accurately determine intake side losses.

The maximum lift, including elevation gain and friction losses, must not exceed the practical limits for pumps. High water velocities or high pressure losses through suction lines can create major problems including cavitation and complete failure of centrifugal pumps.

Guideline

- Maximum intake suction < 60kPa
- Maximum suction velocity < 1.5m/s
  (where pipe sizes are not determined by pressure variation or velocity requirements)

NO SUCTION GAUGE ON PUMP INLET?

With no inlet suction gauge, you can only calculate the headworks efficiency from the pump outlet. (When you complete the pump efficiency test, the intake efficiency will be included as part of the overall pumping plant efficiency calculated.)

ELEVATION CHANGE

Increasing elevation unavoidably requires energy. In determining system efficiency, elevation effects are discounted so the pipe work and other system components can be assessed fairly. The intake elevation is the surface level of the water supply, not the position of the actual intake itself which must be under water.

In this Guideline, elevations in metres are converted to kilopascals (kPa) using specific gravity (SG). The standard factor is SG = 9.8, but if your measurements are less than 95% accurate, you could just multiply metres by 10 to get kilopascals.

HYDRAULIC (MAINLINE) EFFICIENCY

Hydraulic efficiency refers to the proportion of energy lost carrying water from the headworks to the entry to the 'irrigator' itself. The 'irrigator' might be a traveller, a pivot or a block of micro-irrigation. Hydraulic efficiency is an assessment of mainline performance. It can be determined from pressure readings and knowledge of elevation changes.

Guideline

- Mainline friction loss < 100kPa
  (unless there is need to burn off pressure, such as in gravity supplied systems).
- Mainline friction loss 4–12kPa/100m pipe

Higher speeds cause higher friction losses and increase the risk of damage through surges and water hammer. In high sediment conditions, minimum velocities may be needed to avoid blockages.

Large diameter pipes subject to uncontrolled starting and stopping are particularly sensitive. The INZ Code of Practice for Irrigation Design recommends maximum water velocities:

Guideline

Condition / location — Max Velocity

< 150mm diameter pipe

- open end, controlled start & stop < 3.0m/s
- uncontrolled start and stop < 1.5m/s

>150mm diameter pipe

- open ended, controlled start & stop < 2.0m/s
- uncontrolled start and stop < 1.0m/s

Why does efficiency change?

There are two basic reasons why a system is inefficient:

1. it has physically deteriorated, and/or
2. it is not suitable for the required operating conditions (i.e. required flow).

If the losses are higher than expected, assess the cost of efficiency improvement. In some cases, relatively minor changes can give considerable on-going energy savings.

What is excess energy loss costing?

The opportunity cost of inefficiency is calculated from energy cost, energy consumption and the relative efficiency of your system compared to guideline values.

This test does not account for extra capital investment that may be required to reduce losses by using larger pipelines and components.

Determining performance

The efficiency of your delivery system can be estimated from flow rates, pressures and elevation changes. The information should be easy to obtain, and calculations needed are set out below.

What equipment will you need?

- This guide and the worksheet
- Pressure gauge
- Vacuum (suction) gauge
- Tape measure
- Pen or pencil.

Field measurements

- Water meter readings
- Elevation (height) at water level, pump, mainline entry and mainline exit
- Pressure readings at pump inlet and outlet
- Pressure readings at mainline entry and exit.

Table A: Headworks efficiency

The basic question is, “How much of the pressure created is remaining after water passes through the headworks?”

Pressure in the system is the result of pump input and pipeline friction losses, and changes in elevation. Elevation effects are discounted to focus on the efficiency of pipes and components.

Follow the steps in Table A of the Worksheet to calculate the efficiency of your system.

NOTES:

- *Elevation accuracy is important!*
  Work to the nearest tenth of a metre. Remember: 0.1 m is about 1kPa.
  You can use actual elevations above sea level, or just call the water level 100.0m and determine all other elevations relative to that
- ***Intake elevation*** is the surface level of the water supply, not the position of the actual intake itself which must be under water. The level may drop in a well when the system is running
- ***Pump inlet elevation*** is determined relative to the water level at the intake. It will be positive from a bore, but may be negative from a higher dam
- ***Elevation change*** will be usually positive from a bore or river but may be negative from a dam. Multiply metres head by specific gravity to get elevation and pressure both in kilopascals (kPa).
- ***Intake pressure*** is 0kPa unless there is a pre-pump or community pipe providing pressure
- ***Change in head*** combines the effects of elevation and friction and is measured by the difference in pressure on the inlet vacuum gauge and the intake pressure
- ***Friction loss*** is the difference between the change in head and the elevation change. It changes with intake screen size and type and pipe diameter
- ***Mainline entry*** is the point where the headworks stop. It will be after control valves, filters, meters and injection points etc.
- ***Total friction headloss*** combines values from both the inlet and outlet sides of the pump
- ***Headworks efficiency*** is a measure of the amount of energy consumed that is converted to useful work.

Table B: Hydraulic (mainline) efficiency

Hydraulic efficiency asks the same questions about the mainline. It considers friction losses and is calculated from the change in total head and elevation differences between the entry to, and exit from, the mainline.

Follow the steps in Table B of the Worksheet to calculate mainline efficiency.

NOTES:

- *Elevation accuracy is important!*
  As with the headworks measurements, work as accurately as you can, to the nearest 0.1m if possible
- ***Mainline entry pressure and elevation*** are the same as those for the Headworks exit.
  Mainline length is recorded in metres. Friction losses are often considered in 100m lengths of mainline. The calculations have a factor built in to convert headloss per metre to headloss per 100m
- ***Excess mainline friction*** is the difference between the maximum 100kPa for a mainline and the value you calculate for your system
- ***Excess friction loss/100m*** compares the maximum reasonable loss of 12kPa/100m with the value you calculate for your system.

ENERGY COSTS

The excess friction loss (if any) from headworks and from the mainline is combined with the cost of pumping (creating the total energy) determined from the pump efficiency test.

Table C: Pipe velocities

Excess velocity in pipes causes excess friction, and increases the risk of pipe damage from water hammer and other shock loads.

The internal pipe diameter must be known, and is not the ‘nominal diameter’ of the pipe in most cases. Either measure a sample or check with your supplier to ensure you have the right value. Small diameter errors cause big velocity errors.

Pipe section area calculations convert diameters in mm to cross sectional areas in square metres.

Excess velocities are the difference between the recommended maximum values and your results.

Worksheet for Delivery System Efficiency Test

Enter elevations, pressures and other data and complete the Calculations as directed. Enter information using the measurement units (e.g. kilopascals or metres) specified to ensure calculated answers have the correct units. Compare your results with standard recommendations.

TABLE A: HEADWORKS INLET EFFICIENCY

Inlet-side efficiency

a	Water surface elevation when operating – include drawdown (m)	0.0
b	Pump inlet elevation (m)	4.0
c	Change in elevation head (kPa) [(b – a) x SG]	39
d	Water intake pressure (kPa)	0
e	Pump inlet pressure (kPa)	-55
f	Change in pressure head (kPa) [d – e]	55
g	Friction headloss (kPa) [f – c]	16

Outlet-side efficiency

h	Pump outlet elevation (m)	4.0
j	Mainline entry elevation (m)	4.0
k	Change head (kPa) [(h – g) x SG]	0
m	Pump outlet pressure (kPa)	450
n	Pressure at mainline entry (kPa)	425
p	Change in pressure head (kPa) [m – n]	25
q	Friction headloss (kPa) [p – k]	25

Total headworks efficiency

r	Total friction headloss (kPa) [g + q]	41
s	Total pressure head (kPa) [f + p]	80
t	Headworks Efficiency [(s – r) ⁄ s] x 100	49

Excess energy cost

u	Excess headworks friction loss (kPa) [r – 30]	11
v	Excess system friction ratio [u ⁄ s]	0.1345
y	Annual Energy Cost ($ pa) From Pump Efficiency Test	9,846
z	Annual energy loss cost ($ pa) [w x y]	1324.3

TABLE B: MAINLINE EFFICIENCY

a	Mainline entry elevation (m)	4.0
b	Mainline exit elevation (m)	7.0
c	Change in elevation head (kPa) [(b – a) x SG]	29
d	Mainline entry pressure (kPa)	425
e	Mainline exit pressure (kPa)	300
f	Change in head (kPa) [d – e]	125
g	Friction headloss (kPa) [f – c]	96
h	Excess mainline friction (kPa) [100 - g]	4
j	Mainline length (m)	860
k	Friction loss (kPa ⁄ 100m) [g ⁄ j x 100]	11
m	Excess mainline friction (kPa ⁄ 100m) [12 - k]	1

Excess energy cost

n	Excess mainline friction loss (kPa) [greater of h or m]	4
p	Excess system friction ratio [n ⁄ f]	0.032
q	Annual Energy Cost ($ pa) From Pump Efficiency Test	9,846
r	Annual energy loss cost ($ pa) [p x q]	315.07

TABLE C: PIPE VELOCITIES

a	System flow rate (m^3 ⁄ hr)	192
b	Intake pipe internal diameter (mm)	200
c	Intake pipe section area (m^2) [3.14 x (b ⁄ 2000) 2]	0.0314
d	Intake pipe velocity (m ⁄ s) [(a ⁄ 3600) ⁄ c]	1.7
e	Excess intake velocity (m ⁄ s) [d – 1.5]	2.0
f	Mainline internal diameter (mm)	200
g	Mainline section area (m^2) [3.14 x (f ⁄ 2000) 2]	0.0314
h	Mainline velocity (m ⁄ s) [(a ⁄ 3600) ⁄ g]	1.7
j	Standard velocity max for conditions (m ⁄ s) [from Guidelines p2]	860
k	Relative velocity (m ⁄ s) [h - j]	-0.3

Delivery system efficiency worksheet

What is the irrigation test about?

The purpose of this irrigation test is to determine the energy efficiency of the headworks and pipelines feeding the irrigation system. See also the guidelines for fuller explanation of the steps.

If findings are unexpected, or suggest low performance, consider getting professional advice.

When should testing be done?

Complete the efficiency test when commissioning a new system and after any major changes to the pumping or irrigation systems. It should also be repeated as part of annual maintenance.

Make sure the system operation is 'typical' when you test, so your results are meaningful.

What needs to be done?

1. Gather information about the system
2. Record the data on the worksheet
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4. Compare your results with target values.

What equipment will you need?

- This worksheet and the guide
- Pressure gauge
- Vacuum (suction) gauge
- Tape measure
- Pen or pencil.

Field measurements

- Water meter readings
- Elevation at water level, pump, mainline entry and mainline exit
- Pressure readings at pump inlet and outlet
- Pressure readings at mainline entry and exit.

The more accurate your input values, the more accurate your results. Take care reading pressure and determining elevation changes. Use good equipment in good order.

If you don't already have pressure and suction gauges in place, it may take a little setting up the first time you do this testing. Next time, your equipment will already be in place.

What is acceptable?

NOTE:
In this Guideline, elevations in metres are converted to kilopascals (kPa) using specific gravity (SG). The standard factor is SG = 9.8, but if your measurements are less than 95% accurate, you could just multiply metres by 10 to get kilopascals.

HEADWORKS EFFICIENCY

Basic headworks including water meter, clean filters and gate valves, but excluding pressure control valves.

- Maximum friction headloss < 30kPa

INTAKE SIDE / SUCTION LINE

- Maximum intake suction < 60kPa
- Maximum suction velocity < 1.5m/s (where pipe sizes are not determined by pressure variation or velocity requirements)

HYDRAULIC (MAINLINE) EFFICIENCY

- Mainline friction loss < 100kPa (unless there is need to burn off pressure, such as in gravity supplied systems).
- Mainline friction loss 4–12kPa/100m pipe

Situation	Max Velocity
< 150mm diameter pipe	
• open end, controlled start & stop	< 3.0m/s
• uncontrolled start and stop	< 1.5m/s
>150mm diameter pipe	
• open end, controlled start & stop	<2.0m/s
• uncontrolled start and stop	< 1.0m/s

Worksheet for Delivery System Efficiency Test

Enter elevations, pressures and other data and complete the Calculations as directed. Enter information using the measurement units (e.g. kilopascals or metres) specified to ensure calculated answers have the correct units. Compare your results with standard recommendations.

TABLE A: HEADWORKS INLET EFFICIENCY

Inlet-side efficiency

a	Water surface elevation when operating – include drawdown (m)	
b	Pump inlet elevation (m)	
c	Change in elevation head (kPa) [(b – a) x SG]	
d	Water intake pressure (kPa)	
e	Pump inlet pressure (kPa)	
f	Change in pressure head (kPa) [d – e]	
g	Friction headloss (kPa) [f – c]	

Outlet-side efficiency

h	Pump outlet elevation (m)	
j	Mainline entry elevation (m)	
k	Change head (kPa) [(h – g) x SG]	
m	Pump outlet pressure (kPa)	
n	Pressure at mainline entry (kPa)	
p	Change in pressure head (kPa) [m – n]	
q	Friction headloss (kPa) [p – k]	

Total headworks efficiency

r	Total friction headloss (kPa) [g + q]	
s	Total pressure head (kPa) [f + p]	
t	Headworks Efficiency [(s – r) / s] x 100	

Excess energy cost

u	Excess headworks friction loss (kPa) [r – 30]	
v	Excess system friction ratio [u / s]	
y	Annual Energy Cost ($ pa) From Pump Efficiency Test	
z	Annual energy loss cost ($ pa) [w x y]	

TABLE B: MAINLINE EFFICIENCY

a	Mainline entry elevation (m)	
b	Mainline exit elevation (m)	
c	Change in elevation head (kPa) [(b – a) x SG]	
d	Mainline entry pressure (kPa)	
e	Mainline exit pressure (kPa)	
f	Change in head (kPa) [d – e]	
g	Friction headloss (kPa) [f – c]	
h	Excess mainline friction (kPa) [100 - g]	
j	Mainline length (m)	
k	Friction loss (kPa/100m) [g / j x 100]	
m	Excess mainline friction (kPa/100m) [12 - k]	

Excess energy cost

n	Excess mainline friction loss (kPa) [greater of h or m]	
p	Excess system friction ratio [n / f]	
q	Annual Energy Cost ($ pa) From Pump Efficiency Test	
r	Annual energy loss cost ($ pa) [p x q]	

TABLE C: PIPE VELOCITIES

a	System flow rate (m^3/hr)	
b	Intake pipe internal diameter (mm)	
c	Intake pipe section area (m^2) [3.14 x (b / 2000) 2]	
d	Intake pipe velocity (m/s) [(a / 3600) / c]	
e	Excess intake velocity (m/s) [d – 1.5]	
f	Mainline internal diameter (mm)	
g	Mainline section area (m^2) [3.14 x (f / 2000) 2]	
h	Mainline velocity (m/s) [(a / 3600) / g]	
j	Standard velocity max for conditions (m/s) [from Guidelines p2]	
k	Relative velocity (m/s) [h - j]	

Pump efficiency guidelines

What is the irrigation test about?

The purpose of this trrigation test is to determine the energy efficiency of the motor and pump combination feeding the irrigation system.

The test is designed so irrigation managers can do testing and calculations themselves. As well as this guideline, a worksheet is available to assist. If findings are unexpected, or suggest low performance, consider getting professional advice.

A full irrigation pump performance test must be performed by a trained service provider with appropriate testing equipment.

Why check pump performance?

Profitability – Incorrectly sized or physically deteriorated pumps will waste energy and money. A good pumping system saves money!

Sustainability – Efficient pumping minimises energy use and carbon emissions. A good pumping system saves the environment!

Pump and motor selection are important system design considerations. Incorrectly sized pumps and/or motors will not operate at their most efficient points. So they will waste energy.

Low pressure is a common cause of poor irrigation uniformity which reduces overall system effectiveness and efficiency. The pump must provide adequate pressure and flow to ensure the system operates as designed.

Excessive pressure affects performance and wastes energy. Pump selection will usually allow about 5% extra pressure capacity to allow for slippage with time. But excessively oversized pumps are major energy wasters.

What is involved?

Measured flow rates are combined with energy consumption information. This allows calculation of the energy efficiency of the motor and pump combination, operating as tested.

The process should be repeated if there are significantly different operating conditions, essentially varying flow and/or pressure.

NOTE:
Using this method, the intake pipe efficiency is included as part of the overall pump efficiency calculated. In multiple pump systems, it is possible to analyse each pump separately if pressures between pumps can be measured.

What will the testing show?

The main things the calibration test will show are:

- **Energy consumed**
  The kWh or diesel energy used to run the system; hourly and annually.
- **Pump efficiency**
  How much of the energy consumed (and paid for) is used to do useful 'work' driving the irrigation system.
- **Pump performance**
  How well the pump compares with typical values for that type and size of equipment.
- **Annual energy cost and savings**
  How much energy and money would be saved if the pump was operating at typical performance levels.

What needs to be done?

1. Gather information about the system
2. Record the data on the worksheet
3. Calculate answers using the worksheet and guide.

When should testing be done?

Complete the efficiency test when commissioning a new system and after any major changes to the pump or irrigation system. Testing should be repeated as part of system checks at the start of every season. Compare with past results to identify slippage or failures.

What are the test's limitations?

The irrigation pump efficiency test will only provide information for the conditions measured, running at a given flow and pressure with a given depth to water. The energy use and efficiency will change if system pressure or flow changes or if the water table moves up or down.

The efficiency value determined is for the motor and pump combination. It is not easy to separate the individual performance of the motor or the pump. By looking at typical values, some indication is possible.

Get professional help if your results show low efficiency.

What is acceptable?

Using an oversized pump will result in higher operating costs. The pressure at the nozzle (the end nozzle if there is more than one) gives best guidance to adequacy of system pressure.

New pumps may have spare capacity to allow for wear. However, if the system pressure is more than 5% over the sprinkler operating requirement, or if partially closed gate valves or pressure regulators are installed to 'burn-off' pressure, it is likely you are wasting energy and money.

It is usually more economical in the long term to select the most efficient pump, even if it requires higher initial outlay. Replacing incorrectly sized motors or pumps can often have a quick payback.

The efficiencies of both the pump itself and the motor are combined for overall efficiency. So, for example, a 90% efficient motor on a 70% efficient pump is only 63% efficient overall ($0.9 \times 0.7 = 0.63$).

Check manufacturer's data sheets to determine the expected efficiency of your pump-motor combination. They should be selected to operate at or near their maximum efficiency points as much as possible.

Table 1 gives guidelines for expected efficiencies, based on motor size and assuming the pump is matched appropriately to the motor.

Why does efficiency change?

There are two basic reasons for a pump being inefficient:

1. it has physically deteriorated, and/or
2. it is not suitable for the required operating conditions (i.e. required flow and pressure).

Most irrigation systems are powered by electric motors or internal combustion engines, sometimes both.
In general, electric motors are more energy efficient than diesel engines, which are usually more efficient than petrol engines.

Differences in potential efficiencies between standard electric motors are generally small (1–5%), but as the motor is at the start of the drive train the savings achieved by an efficient motor and motor operating at its best efficiency point can be substantial.

Changing flow or pressure requirements will change the pump operating point, and can move from its optimum to a less efficient performance.

If pump loads fluctuate widely or if pumps are often run at partial loads, adding a variable speed drive may be cost effective since it closely matches output to actual demand. An alternative is to use multiple pumps turning on or off to optimise to different operating conditions.

Table 1. Typical electric motor and pumping plant efficiencies by motor size

Electric motor kW	Efficiency % of full load motor	Efficiency % of correctly matched pump	Overall efficiency % pump & motor
2 – 4	80 – 86	55 – 65	44 – 56
5 – 7.5	85 – 89	60 – 70	51 – 62
10 – 22	86 – 90	65 – 75	56 – 68
30 – 45	88 – 92	70 – 80	62 – 74
> 55	90 – 93	75 – 85	68 – 79

Source: North Carolina Cooperative Extension Service, Publication Number: AG 452-6

NOTES:

Pump type variations:

1. Values shown are typical for centrifugal pumps.
   - Under 55kW submersible pumps range 3–5% higher and turbine pumps range 5–10% higher.
   - Above 55kW, centrifugal pumps may approach efficiencies of 88%, whereas large submersible and turbine pump efficiencies peak at about 90%.
2. Overall Pump Efficiency ranges are obtained by multiplying the Full Load Motor Efficiency range by the Matched Pump Efficiency range e.g. 80% × 55% = 44% (on a calculator $0.80 \times 0.55 = 0.44$)

Converting values for typical fossil fuels to usable energy values:

1. NZ Diesel contains 10.4kWh per litre but only about 3.5–4.0kWh / L of useful energy are generated
2. NZ 91 Petrol contains 9.69kWh per litre but only about 2.5–2.8kWh / L of useful energy is generated.

The usable energy values for diesel and petrol above are already adjusted for engine efficiency.

If using them as 'Power Conversion' factors in Step 1B: Fossil Fuel, use values from the Matched Pump Efficiency column rather than the Overall Pump Efficiency column as the 'Typical' Pumping Plant Efficiency in Step 4.

Example worksheet for Pump Efficiency Test

Enter times, meter readings, elevation and pressure data. Complete the calculations as directed. Enter information using the measurement units (e.g. kWh or metres) specified to ensure calculated answers have the correct units.

Determining performance

The effective efficiency of your pump and motor combination can be estimated from power readings, flow rates and pressures. The information should be easy to obtain, and calculations needed are set out below.

What equipment will you need?

- This guide and the worksheet
- Stop watch
- Measuring jug (for fuel tank topping)
- Pressure gauge
- Tape measure
- Pen or pencil.

Field measurements

- Test duration
- Power meter readings
- Fuel used
- Water meter readings
- Pressure generated
- Height from water level to pump outlet.

Step 1: Energy use

The rate of energy use is measured in kilowatts (kW) and whether your pump runs on electricity or fuel or both, you need to calculate the kilowatt consumption.

If you have more than one pump, add the energy use rates to get a total. It doesn't matter if you have a combination of electric and diesel, because we calculate energy use rate in the same units (kW).

A Electricity meters show energy consumption in kilowatt hours (kWh) – the combination of energy use rate (kW) and time (hours). Watch though, many have a 'multiplier value' you must include.
Divide kilowatt hours consumed by hours taken to calculate the kilowatts. (kWh / h = kW).

B Diesel and petrol engine fuel use is most easily measured by measuring the amount required to refill the tank. Do this accurately after a set running time. Convert fuel energy to kWh equivalent values.

Step 2: Water consumption

Hopefully there is a correctly calibrated water meter in the system to show flow rate.

If so; follow **Step 2** to record and calculate water use.

If not; determine flow rate from field measurements by doing an irrigation calibration.

Step 1 A: Electricity		Pump 1	Pump 2
a	Test Duration (hours)	1.0	
b	Meter kWh Start	34,657.6	
c	Meter kWh End	34,712.5	
d	Meter kWh Used [c – b]	54.7	
e	Meter Multiplier	1.0	
f	Energy Used / Hour (kW) [d x e / a]	54.7	
g	Energy Cost ($ / kWh)	0.12	
h	Annual Run Time (h)	1,500	
i	Annual Energy Use (kWh) [f x h]	82,050	
k	Annual Energy Cost ($ pa) [g x j]	9,846	

Step 1 B: Fossil Fuel		Pump 1	Pump 2
a	Test Duration (hours)	1.0	
b	Fuel Used (L)	20.0	
c	Energy Conversion (kWh/L) [from Table 1]	4.0	
e	Fuel Cost ($/L)	1.1	
f	Energy Used / Hour (kW) [b x c / a]	80.0	
g	Energy Cost ($ / kWh) [e / f]	0.275	
h	h Annual Run Time (h)	1,500	
j	Annual Energy Use (kWh pa) [f x h]	33,000	
k	Annual Energy Cost ($ pa) [g x j]	9,075	

Step 2: Water Use

a	Test Duration (hours)	1.0
b	Meter m^3 Start	4,126,585
c	Meter m^3 End	4,126,712
d	Meter m^3 Used [c – b]	192
e	Meter Multiplier	1.0
f	Water Used $(m)^3$ [d x e]	192
g	Water Flow Rate (m^3/h) [f / a]	192
h	Annual Run Time (h)	1,500
j	Annual Water Use (m^3 pa) [g x h]	288,000

Step 3: Rate of work done

The rate of work done by a pump is calculated from the water flow rate, lift (change in elevation × specific gravity) and increase in Pressure Head.

ELEVATION HEAD (LIFT)

Elevation head refers to the lift from the source water level to the pump discharge. It is the lift from the actual water level when the pump is running (drawn down) to the centre of the pump outlet.

Elevation head is usually positive, but if the water level is higher than the pump (e.g. a dam), the elevation change is recorded as a negative value.

Specific Gravity (SG) accounts for the force of gravity. SG = 9.8, but you could just multiply metres elevation change by 10 to get approximate kilopascals Head.

In these calculations, a further adjustment of 3600 is required to convert flow per hour to flow per second.

PRESSURE HEAD INCREASE

The system intake is usually not pressured. (Water depth above intakes or submerged pumps is taken into account already, as we measure from the water surface level to the pump for Elevation Head.)

However, if there is positive head on the intake from a primary pump, this pressure needs to be subtracted to get the increase in pressure generated by the pump you are testing.

The pump is working to overcome friction in the intake side of the headworks. To account for this, add the friction determined using the delivery system efficiency guidelines.

OUTLET PRESSURE

The outlet pressure is read directly from a pressure gauge mounted at the pump outlet. Most systems have this facility, but make sure the gauge is in good condition.

Replace it if necessary.

Step 4: Pump efficiency

Pump efficiency shows how much of the energy consumed does useful work. It is usually given as a percentage.

In the examples here, energy use rate (kW) is easily compared to calculated work done. (The example calculation values in Fossil Fuel Use are ignored.)

RELATIVE PERFORMANCE

Select a reasonable value for your situation from Table 1 and compare it with the calculated efficiency for your actual pumping plant. The relative performance is usually given as a percentage.

Efficiency cost

The potential savings are calculated from the annual cost and the relative performance value determined.

In the worked example, the cost of energy for a pumping plant with 48.6% efficiency is 44% more than a typical plant running at 70% efficiency.

Step 3: Work Done

a	Elevation Change (m)	7
b	Elevation Head (kPa) [a x SG]	69
c	System Intake Pressure (kPa)	0
d	Pump Outlet Pressure (kPa)	414
e	Pressure Head (kPa) [d – c]	414
f	Inlet-side Friction (kPa) [from Delivery Efficiency Worksheet]	16
g	Total Dynamic Head (kPa) [b + e + f]	499
h	Water Flow Rate (m^3/h) [g from Step 2]	192
j	Work Done (kW) [g x h / 3600]	26.6
k	Design Outlet Pressure (kPa) [from Design Details]	430
m	Outlet Pressure Deviation (kPa) [d – k]	-16
n	Outlet Pressure Deviation % [m / k x 100]	-3.7

Step 4: Pump Efficiency

a	Electric Power(kW) [from Step 1 A: f]	54.7
b	Fossil Fuel Power (kW) [from Step 1 B: d]	OPTION
c	Total Power (kW) [a + b] 54.7	54.7
d	Work Done (kW) [from Step 3: j]	26.6
e	Overall Pump Efficiency % [d / c) x 100]	48.6
f	Typical Efficiency [from Table 1]	70.0
g	Relative Performance % [e / f x 100]	69.4

Efficiency Cost

h	Electricity Cost ($ pa) [from Step 1 A: j]	9,846
j	Fossil Fuel Cost ($ pa) [from Step 1 B: h]	OPTION
k	Total Energy Cost ($ pa) [h + j]	9,846
m	Typical Efficiency Cost ($ pa) [k x g / 100]	6,833
n	Annual Cost Saving ($ pa) [k – m]	3,013
p	Annual Water Use (m^3 pa) [from Step 2: j]	288.000
q	Pumping Energy Cost ($/$m^3$) [k / p]	0.034
r	Power Demand (kW/m^3) [Step 1: f / Step 2: g]	0.284

Pump efficiency worksheet

What is the irrigation test about?

The purpose of this irrigation test is to determine the energy efficiency of the motor and pump combination feeding the irrigation system.

The test is designed so irrigation managers can do testing and calculations themselves. As well as this worksheet, a guideline is available to assist.

Determining performance

The effective efficiency of your pump and motor combination can be estimated from power readings, flow rates and pressures. The information should be easy to obtain, and calculations needed are included in the tables and explained in the Guidelines.

What needs to be done?

1. Gather information about the system
2. Record the data on the worksheet
3. Calculate answers using the worksheet & guide

When should testing be done?

Complete the efficiency test when commissioning a new system and after any major changes to the pump or irrigation system.

Testing should be repeated as part of system checks at the start of every season. Compare with past results to identify slippage or failures.

Equipment you will need

- This worksheet and the guidelines
- Stop watch
- Measuring jug (for fuel tank topping)
- Pressure gauge
- Tape measure
- Pen or pencil.

Field measurements

- Test duration
- Power meter readings
- Fuel used
- Water meter readings
- Pressure generated
- Height from water level to pump outlet.

Step 1: Energy use

For each pump, calculate energy use rate in kW. Add energy use rates of multiple pumps to get the total.

A Electricity meters show energy consumption in kilowatt hours (kWh). Include any 'multiplier value'. Divide kilowatt hours consumed by hours taken to calculate the kilowatts. (kWh / h = kW).

B Diesel and petrol engine fuel use must be converted to kWh equivalent values.

Step 2: Water consumption

Follow Step 2 to record and calculate water use.

If no meter: Determine flow rate by doing an irrigation calibration.

Step 3: Rate of work done

The rate of work done by a pump is calculated from the water flow rate, lift (change in elevation × specific gravity) and increase in Pressure Head.

ELEVATION HEAD (LIFT)

Elevation head is the lift from drawn down water level to centre of pump outlet. Usually positive, but negative if water level is higher than the pump.

Specific Gravity (SG) accounts for the force of gravity. Divide by 3600 to convert flow/hour to flow/second.

PRESSURE HEAD INCREASE

If there is positive head on the intake from a primary pump, subtract it to get pressure generated by pump.

If possible, add the intake pipe friction determined using the delivery system efficiency test.

OUTLET PRESSURE

Read directly from a pressure gauge at pump outlet. Ensure gauge is in good condition. Replace it if not.

Step 4: Pump efficiency

Shows how much of the energy consumed does useful work. It is usually given as a percentage.

RELATIVE PERFORMANCE

Select a reasonable value for your situation from Guidelines Table 1 and compare it with the calculated efficiency for your actual pumping plant. The relative performance is usually given as a percentage.

EFFICIENCY COST

The potential savings are calculated from the annual cost and the relative performance value determined.

Worksheet for Pump Efficiency Test

Enter times, meter readings, elevation and pressure data. Complete the calculations as directed. Enter information using the measurement units (e.g. kWh or metres) specified to ensure calculated answers have the correct units.

Step 1 A: Electricity

		Pump 1	Pump 2
a	Test Duration (hours)		
b	Meter kWh Start		
c	Meter kWh End		
d	Meter kWh Used [c – b]		
e	Meter Multiplier		
f	Energy Used / Hour (kW) [d x e / a]		
g	Energy Cost ($ / kWh)		
h	Annual Run Time (h)		
i	Annual Energy Use (kWh) [f x h]		
k	Annual Energy Cost ($ pa) [g x j]		

Step 1 B: Fossil Fuel

		Pump 1	Pump 2
a	Test Duration (hours)		
b	Fuel Used (L)		
c	Energy Conversion (kWh/L) [from Table 1]		
e	Fuel Cost ($/L)		
f	Energy Used / Hour (kW) [b x c / a]		
g	Energy Cost ($ / kWh) [e / f]		
h	h Annual Run Time (h)		
j	Annual Energy Use (kWh pa) [f x h]		
k	Annual Energy Cost ($ pa) [g x j]		

Step 2: Water Use

a	Test Duration (hours)	
b	Meter m^3 Start	
c	Meter m^3 End	
d	Meter m^3 Used [c – b]	
e	Meter Multiplier	
f	Water Used $(m)^3$ [d x e]	
g	Water Flow Rate (m^3/h) [f / a]	
h	Annual Run Time (h)	
j	Annual Water Use (m^3 pa) [g x h]	

Step 3: Work Done

a	Elevation Change (m)	
b	Elevation Head (kPa) [a x SG]	
c	System Intake Pressure (kPa)	
d	Pump Outlet Pressure (kPa)	
e	Pressure Head (kPa) [d – c]	
f	Inlet-side Friction (kPa) [from Delivery Efficiency Worksheet]	
g	Total Dynamic Head (kPa) [b + e + f]	
h	Water Flow Rate (m^3/h) [g from Step 2]	
j	Work Done (kW) [g x h / 3600]	
k	Design Outlet Pressure (kPa) [from Design Details]	
m	Outlet Pressure Deviation (kPa) [d – k]	
n	Outlet Pressure Deviation % [m / k × 100]	

Step 4: Pump Efficiency

a	Electric Power(kW) [from Step 1 A: f]	
b	Fossil Fuel Power (kW) [from Step 1 B: d]	
c	Total Power (kW) [a + b] 54.7	
d	Work Done (kW) [from Step 3: j]	
e	Overall Pump Efficiency % [d / c) × 100]	
f	Typical Efficiency [from Table 1]	
g	Relative Performance % [e / f × 100]	

Efficiency Cost

h	Electricity Cost ($ pa) [from Step 1 A: j]	
j	Fossil Fuel Cost ($ pa) [from Step 1 B: h]	
k	Total Energy Cost ($ pa) [h + j]	
m	Typical Efficiency Cost ($ pa) [k x g / 100]	
n	Annual Cost Saving ($ pa) [k – m]	
p	Annual Water Use (m^3 pa) [from Step 2: j]	
q	Pumping Energy Cost ($/$m^3$) [k / p]	
r	Power Demand (kW/m^3) [Step 1: f / Step 2: g]	