New Zealand Piped Irrigation System Performance Assessment Code of Practice

PART H: Pivot

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

Part H: Contents

Date of Issue: January 2023

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
(Part H = this booklet)
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

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

Ministry for Primary Industries
Manatū Ahu Matua

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Introduction

Purpose

The *New Zealand Piped Irrigation System Performance Assessment Code of Practice* provides nationally recognised guidelines to measure and benchmark performance of agricultural irrigation.

Part H is specific to centre pivot irrigation systems. It makes recommendations for planning and conducting assessments and reporting on the performance of irrigation systems and their management. Its focus is on key performance indicators that are common with the New Zealand Piped Irrigation Systems Design Standards..

It was developed to provide guidelines for irrigators and others undertaking evaluations of such equipment as a 'snapshot exercise' under prevailing field conditions.

SYSTEM PERFORMANCE

The Code recognises different levels of performance assessment depending on purpose. In increasing level of complexity, system performance assessment includes:

- Operational Checks
- System Calibration
- In-field Performance Assessment.

Related documentation

- **New Zealand Piped Irrigation System Performance Assessment Code of Practice:**
  - 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 makes recommendations for checks to ensure compliance with regulations, rules and consent conditions, safe effective operation of water supply systems and energy efficiency assessments of pumps and delivery systems.
  - Parts C–H: System Performance Assessments
    Parts C–H contains guidelines and recommendations for performance assessments specific to a range of irrigation system types.
- **New Zealand Piped Irrigation Systems Design Code of Practice**
- **New Zealand Piped Irrigation Systems Design Standards**
- **New Zealand Piped Irrigation Systems Installation Code of Practice**
- **New Zealand Water Measurement Code of Practice**
- **New Zealand Irrigation Technical Glossary**

System description

A centre pivot machine consists of a lateral circulating around a fixed pivot point. The lateral is supported above the field by a series of A-frame towers, each having two driven wheels at the base. Depending on field layout, the pivot may complete a full circle or only part segments.

Water is discharged under pressure from sprinklers or sprayers mounted on the lateral as it sweeps across the field. As such, the evenness of application at points along the lateral, and the evenness of application as the lateral passes across the field both contribute to overall irrigation distribution uniformity.

Because of the very low labour requirement per irrigation, centre pivots allow farmers to apply frequent light irrigations as needed to best fit crop water requirements and maximise production.

Special features for analysis

DISCHARGE RATES ALONG THE LATERAL

The unique and critical feature of a centre pivot machine is how it moves across the field. The centre pivot lateral moves at increasing ground-speed with distance for the centre, so the application *intensity* must increase further out along the lateral to give the same application *depth*.

Any point-measurement, such as collector (catch-can) volume, is representative of a much larger area of the entire field. Under a centre pivot, the collector measurements at the outer end represent a very much larger area of the field than those near the centre.

STOP-START OPERATION

The speed of rotation of a centre pivot is generally controlled by varying the average speed of the end tower. For electric machines, this is achieved by cycling the power on and off using a percentage timer mounted at the pivot end. Typically the cycle time is one minute. A 25% speed is achieved by turning the end-tower drive-motor on for 15 seconds every minute.

Irrigator alignment is maintained by operating inner towers for proportionally shorter times, so the forward movement of these machines is unsteady. This stop-start operation can result in non-uniform application along the travel path, especially for single irrigation events. Because the stopping points are effectively random, this is mostly mitigated by subsequent irrigation cycles (CPD).

Field evaluation should attempt to minimise effects of single event stop-start effects on distribution measurements which otherwise lead to underestimates of distribution uniformity. For a single radial test this may require operating the machine at 100% speed to minimise the number and duration of stop-starts. Alternatively, multiple radial measurements can be used.

Hydraulically powered centre pivot machines should run more smoothly but assessors are advised to still pay attention to the possibility of erratic movement and potential effects on uniformity.

VARIABLE RATE SYSTEMS

Variable rate systems allow different parts of the irrigated area to receive different depths of irrigation. This is achieved by switching individual nozzles on and off in accordance to an application plan or map. Testing such machines requires care to ensure the intended depth at any location is known.

FIELD VARIABILITY

The performance of a centre pivot irrigation machine may vary at different positions in the field. Contributing factors include topographic variation and elevation changes, wind effects, and the operation of various add-on components such as end guns or corner swing arms.

A machine without add-on equipment, operating on a relatively flat, homogenous field should have similar performance in all positions. The assessor and client should discuss what testing is desired and the conditions under which any tests should be conducted.

WIND EFFECTS

The performance of pressurised spray systems can be greatly affected by wind, particularly when nozzles create smaller droplet sizes. Strong cross winds are likely to have greatest effects.

The uniformity testing should be carried out in conditions representative of those commonly experienced in the field. Wind speed and direction should be measured and recorded.

1. Operational checklist

This is a minimum list of checks of centre pivot irrigation machines that should be made.

Be safety conscious – electrical and mechanical hazards may be present.

Every system should be supplied with a System Operation Manual. The manual may include extra checks not listed here. It will give more detail than this checklist including information specific to your system.

SYSTEM OFF CHECKS

Pivot point

1. Check condition of seals
2. Pressure gauge fitted and in good condition
   - Lubricate as specified in manual.

Towers

3. Check U joints for wear
   - Replace if necessary
4. Visually check Cable and rod connections
5. Visually check Wheel lug bolts, tyre condition and pressure
6. Visually check Gearboxes, drive shafts
   - Lubricate as required.
7. Visually check Riser and spans
8. Visually check Boots
   - Tighten bands if necessary.
9. Flanges

End gun, corner arms

10. Check connections
11. Visually check wiring and hydraulic lines

Sand trap

12. Empty and flush

Sprinklers

13. Check sprinklers fitted are as specified in sprinkler chart
    - Replace as necessary.

NOTE:
Sprinkler bases are colour coded.

NOTE:
LINEAR MOVES – all sprinklers are usually identical.
CENTRE PIVOTS – all sprinklers are usually different.

14. Inspect nozzle orifice condition
    - Replace if wear detectable
15. Ensure rotating nozzles are free turning and cages not damaged
16. Inspect droppers for wear or damage
    - Replace as necessary.

Gun

17. Check gun components for looseness, freedom of movement
18. Check gun outlet nozzle orifice condition
    - Replace if wear detectable.

Control unit

19. Visually inspect electronic controls
20. Check battery charge.

SYSTEM ON CHECKS

WARNING:
Before starting ensure nothing is parked in front of the irrigator.

Pump

1. Complete checks as specified earlier in Section 1

Pipe network

2. Check for leaks along mainline

System pressure

3. Check pump pressure while system operating
4. Check pressure before and after filters

Off-takes/hydrants (linear moves and towable pivots)

5. Check hydrants are not leaking

Drag hose

6. Check there are no leaks
7. Check the hose is not misshapen

Pivot point

8. Check for leaks, movement

Riser and spans

9. Check inlet pressure gauge with alternative
   - Replace if necessary.
10. Check inlet pressure is correct

    NOTE: Hydrant must be in use to get valid pressure reading.

    NOTE: Check farthest and highest hydrant positions to ensure adequate pressure.
11. Check for leaks along spans and at towers
    - Check flanges: call service company if flanges leaking.

Towers

12. Observe motors, gear box and drive shaft operation for noise or vibration

Droppers

13. Check for leaks
    - Repair or replace as necessary.

Sprinklers

14. Check each sprinkler is turning correctly and cage not damaged
    - Repair or replace as necessary.
15. Check there are no leaks
    - Repair or replace as necessary.
16. Check the pressure above last sprinkler, above pressure regulator if fitted

NOTE:
This requires installation of a test point. A ¾" BSP Tee above the pressure regulator is usually suitable. Reduce to ¼" BSP for standard pressure gauge.

Gun

17. Check gun is operating correctly
18. Check gun angles are correct, gun switches direction at correct locations

Corner arm

19. Check arm tracks correctly
20. Check sprinklers turn on and off correctly

Control unit

21. Check any control unit is functioning correctly

2. Calibrating centre pivot irrigators

The Irrigation Calibration method for Centre Pivot irrigators assesses the amount of water being applied during an irrigation event. It is based on measurement water collected in a line of containers spaced across the path of travel. Applied Depth, Application Intensity and Distribution Uniformity are calculated.

This allows the manager to determine the speed required to apply the target depth, and whether the system is applying the same amount of water at all points along the machine. A plan to apply target depths can be determined.

2.1 What will the testing show?

The main things the calibration test will show are:

Applied depth
The 'rainfall equivalent' depth of water the irrigation system is applying on average at the particular travel speed. Compare the measured applied depth to target application to determine machine speed adjustment to correct applied depths.

Application intensity
The rate (mm/hour) at which water is being applied, equivalent to rainfall intensity. If intensity exceeds soil infiltration capacity, ponding, bypass flow, redistribution and runoff will reduce irrigation effectiveness and efficiency.

NOTE: The Application Intensity of Centre Pivot irrigators increases along the length of the machine. Rates are low (gentle) at the inner spans, increases to high (intense) at the end. This protocol calculates Application Intensity at the end tower, the highest rate but one representing a large proportion of the irrigated area.

Distribution uniformity DU
Distribution Uniformity describes the evenness with which water is applied. The higher the DU the better the system is performing. And the higher the uniformity, the more confident you can be that your measurements are truly representative of your system's performance.

Excess water use EWF
The excess water use factor identifies how much extra water is required during a set event because of non-uniformity.

Adjusted machine speed
Calculates the machine speed required to ensure 7/8ths of the area gets at least the Target Application Depth. It accounts for flow rate and uniformity.

WHEN SHOULD CALIBRATION BE DONE?

Complete the calibration test if commissioning a new machine and after any major changes.

Calibration should be repeated as part of system checks at the start of every season.

NOTE: Centre pivot irrigator irrigation depth is controlled by machine speed. Checking at 100% speed may give best results. If the machine stops for long periods it may affect bucket collected volumes.

NOTE: Centre pivot irrigator performance can be significantly affected by weather conditions. Consider wind conditions when testing: Calm conditions may give a better assessment of the system's potential performance but if wind is normal for the site, testing may proceed.

NOTE: The flow and uniformity of a centre pivot will not normally change much if adequate pressure is supplied. Check end sprinkler pressure:

- at different hydrant positions
- different field elevations or
- when alternative water-takes reduce system pressure.

2.2 Calibration process

Before starting, ensure System Operational Checks (Section 1) have been completed.

Calibration is a four step process:

1. Gathering information about the system
2. Calculating performance indicator values
3. Comparing results with expectations
4. Adjusting irrigation system settings as required to achieve intended performance.

GATHERING INFORMATION

Equipment

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

- 24 containers of same known opening diameter (>150 mm)
  - 9 Litre buckets have been found suitable
  - 1 or 2 Litre for larger volumes (large collectors, higher application depths)
  - 100mL or 200mL for smaller volumes (small collectors, lower application depths)
- 1 tape measure (20m)
- 2 flags or fence standards
- 1 stop watch
- 1 pen or pencil
- 1 recording sheet.

Sampling method

The calibration check is based on a line of collectors (transects) placed across the travel path. It can be useful to repeat the test at different positions around the circle to check performance is consistent. Changing terrain or end-guns turning on and off can affect machine performance.

Testing layout

1. Set 24 collector buckets in a row along the length of the irrigator, starting a fifth of the way along the length of the irrigator
2. Arrange twelve collector buckets at even spacing from this point to two thirds of the irrigator length (see 1–12 in Figure 2.1).
3. Arrange ten more buckets at even spacing from two thirds of the irrigator length to the end wheels (see 13–22 in Figure 2.1). The spacing will be different to the first twelve buckets.
4. Arrange two buckets at even spacing between the end wheel track and the extent of significant wetting (see 23–24 in Figure 2.1).

   NOTE: The end section may be a part span or an end-gun or both. Avoid the very end where application drops quickly away.

Mark speed test positions

5. Place two marker flags along the line of travel, either side of the collector bucket transect
6. Record the distance between the flags

   NOTE: Put flags at least 5 m either side of the line of collector buckets near the machine end-tower.

   NOTE: Ensure marker flags are visible from outside the wetting area so they can be seen during testing.

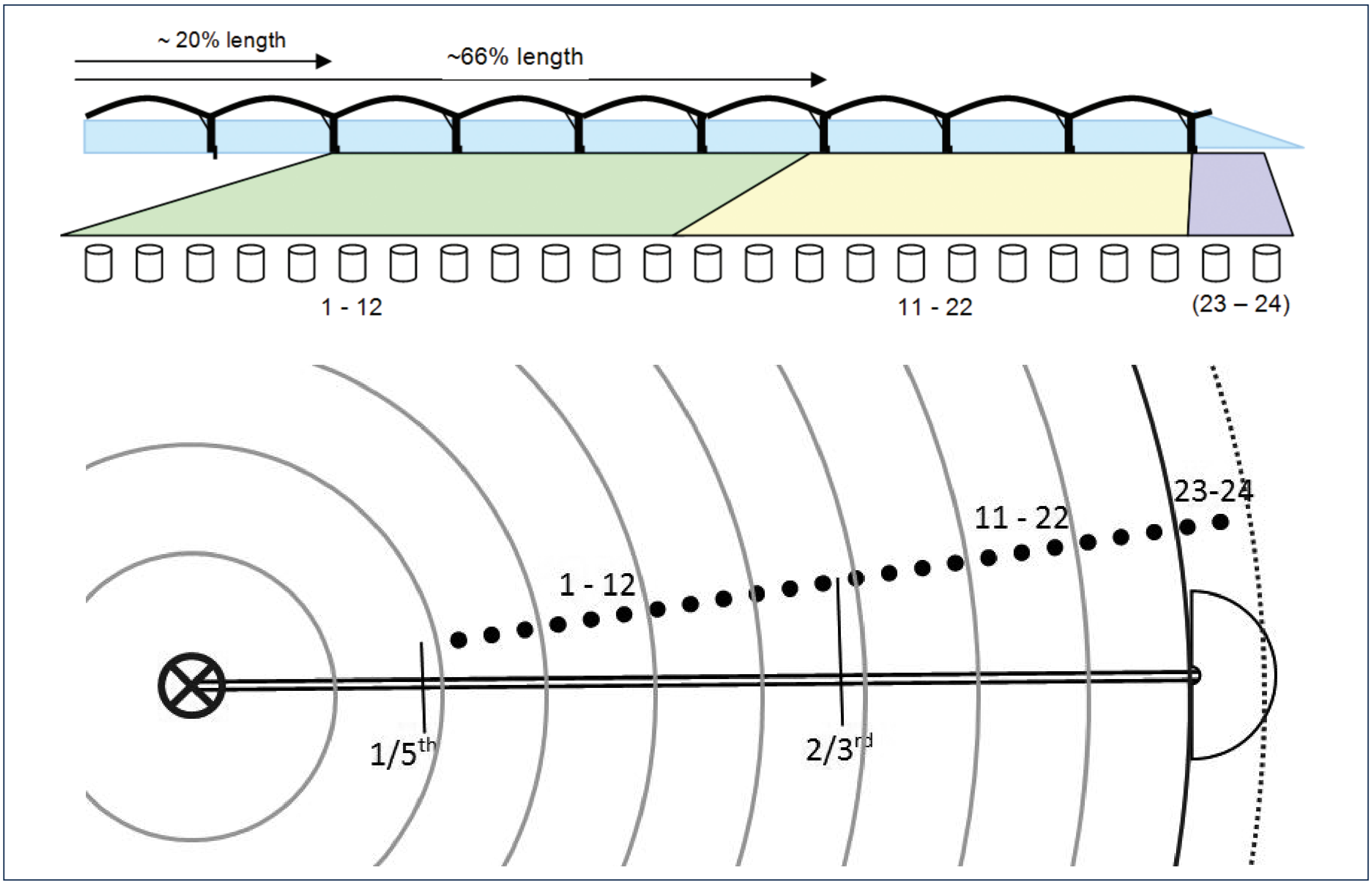

Figure 2.1. Layout of collectors along length of centre pivot irrigator.

FIELD MEASUREMENTS

Management information

1. Record the Target Irrigation Depth
2. Record the Irrigator Speed Setting
3. Record the number of Circles or Part Circles

System measurements

4. Measure the system Flow Rate
5. Measure the Outlet Pressure at the pump
6. Measure the Pressure at the Entry to the irrigator
7. Measure the Pressure the last tower

   NOTE: Take pressure measurement above any pressure regulator at the nozzle at the tower.

Application test

8. Record the time for the machine to pass between the speed test marker flags
9. Measure the collector bucket mouth diameter
10. Measure the volume of water caught in each container and record on the Record Sheet.

    NOTE: Take care to record each reading in the correct position.

CALCULATE PERFORMANCE INDICATOR VALUES

Irrigator speed

1. Speed (m/min) = Distance travelled ÷ Time taken
   - Distance travelled (m) = distance between marker flags
   - Time taken (min) = Time at second marker flag – Time at first marker flag

Applied depth

2. Calculate Average Applied Depth (mm) [Average Volume collected ÷ Collector opening area]
   - Average Volume Collected (mL) = Sum of all collected ÷ number of collectors
   - Collector opening area (m^2) = Pi x Collector diameter (m) x Collector diameter (m) ÷ 4
3. Calculate Applied Depth (mm) of twelve inner collected depths 1–12
4. Calculate Applied Depth (mm) of twelve outer collected depths 13–24
5. If present; Calculate Applied Depth (mm) of two collected depths under end span/end gun

Application intensity

6. Calculate Application Intensity at End Wheels (mm/h) [Applied Depth (mm) x Irrigator Speed at End Wheels (m/min) x 60 ÷ Wetting Pattern Width at End Wheels (m)]

System flow rate

7. Calculate Flow Rate (L/s) [(Machine Length + End Gun Extra Length) (m) x Applied Depth (mm) x Irrigator Speed (m/min) ÷ 60]

Distribution uniformity

8. Calculate the Distribution Uniformity DU [Low quarter average volume ÷ average volume]
   - Low Quarter Average Volume (mL) = Average of the lowest five collected volumes

Excess water use EWF

9. Calculate Excess Water Use Factor (%) [DU Adjusted Depth ÷ Applied Depth x 100]
   - DU Adjusted Depth (mm) = (Applied Depth ÷ DU) – Applied Depth.

COMPARE RESULTS WITH EXPECTATIONS

Flow rates

1. Compare calculated System Flow Rate with Water Meter Flow Rate

Applied depth

2. Calculate Target Depth to Applied Depth ratio
   = Target Depth ÷ Applied Depth
   a. < 1 – under applying
   b. = 1 – correct
   c. > 1 – over applying

   Acceptable variances: 0.90–1.10 (0.95–1.05 is better)
3. Compare Applied Depth with Soil Moisture Deficit
   - Applied Depth < Soil Moisture Deficit ÷ DU

Application intensity

4. Compare the calculated Application Intensity to expectations

Distribution uniformity DU

5. Interpret calculated DU value
   - DU > 0.90 Uniformity is very good
     the system is performing very well
   - 0.90 – 0.80 Uniformity is good
     performance better than average
   - 0.80 – 0.70 Uniformity is fair
     performance could be improved
   - 0.70 – 0.60 Uniformity is poor
     system should be investigated
   - DU < 0.60 Uniformity is unacceptable
     system must be investigated

ADJUST IRRIGATION SYSTEM SETTINGS

Check key performance indicators

1. If Applied Depth or Uniformity are unacceptable
   - Repeat Operational Checks
   - Ensure system is at recommended operating pressure
   - Get professional assistance.

Irrigator speed

2. Calculate Adjusted Speed (m/min)
   - Irrigator Speed x (Target Depth ÷ DU) ÷ Applied Depth.

   NOTE: Including DU ensures the irrigator applies sufficient extra water to adequately irrigate 7/8th plants.

3. Performance assessment of centre pivot irrigation machines

This schedule outlines procedures to be followed when assessing distribution uniformity of a centre pivot irrigation machine fitted with overlapping sprayers or sprinklers. It was developed to provide guidelines for irrigators and others undertaking evaluations of such equipment as a 'snapshot exercise' under prevailing field conditions.

The guidelines presented in this schedule are not intended for evaluations of centre pivots without overlapping sprinklers, such as the LEPA system which is not used in New Zealand.

NOTE:
Complete Operational Checks (See Section 1) before commencing a system evaluation.

TECHNICAL MATERIALS – RELEVANT STANDARDS

ANSI/ASAE S436.1 DEC01 Test procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles (ANSI)

ISO 11545: 2001 Agricultural irrigation equipment – Centre-pivot and moving lateral irrigation machines with sprayer or sprinkler nozzles – Determination of uniformity of water distribution (ISO)

ISO 8224/1 – 1985 Traveller irrigation machines – Part 1: Laboratory and field test methods

ISO 7749-2: 1990 Irrigation equipment – Rotating sprinklers – Part 2: Uniformity of distribution and test methods

TECHNICAL REFERENCES

Allen, R.G., J. Keller and D. Martin. 2000. *Center Pivot System Design*. The Irrigation Association. Falls Church, VA. (CPD)

3.1 Data collection

This schedule outlines procedures to be followed when assessing performance of centre pivot irrigation machines under prevailing field conditions.

Because test conditions will vary, key conditions must be measured and recorded to assist any comparisons between subsequent tests of the same machine, or when benchmarking against other systems.

NOTE:
To provide a farmer with general operation/management information, test conditions should be representative of those experienced in normal operation.

NOTE:
For System Commissioning or fulfilling specific purchase contract criteria, adherence to test condition limitations such as wind speed should be ensured.

TEST SITE

Location
Select a test location that is most representative of the system as a whole.

If the irrigation site is not level, conduct the test in an area having elevation differences that are within the design specifications of the sprinkler package.

Site variability
If site elevation varies significantly, consider multiple tests to increase accuracy of distribution uniformity assessments. This may involve several radial uniformity tests in different parts of the field.

NOTE:
Some protocols recommend a "Circular Uniformity Test" performed by arranging a circle of collectors around the pivot. This protocol instead recommends multiple lateral uniformity tests if performance at different positions is suspect. Check pressure is adequate in all machine positions and monitor machine speed.

SYSTEM SURVEY

System layout

1. Prepare a map of the system recording the headworks, mainline, pivot centre and position of test

Topography

2. Determine elevation differences between test sites and across the station as a whole.
   - Prepare a sketch of the profile along a typical lateral.

Machine length

3. Measure the machine length and the length of each span, measuring between towers

Un-irrigated length

4. Determine the length of any sections of the machine excluded from irrigation

End gun wetted radius

5. Determine the effective wetted radius of any end gun (or guns) fitted to the machine

Effective radius (R_E)

6. Measure the effective radius from pivot centre (Figure 2.1 Layout of collectors along length of centre pivot irrigator)

Corner system wetted radius

7. Determine the effective wetted radius at full extension of any corner system fitted to the machine. Determine where it may be operative.

Off-target application (F_{TARGET})

8. Estimate the proportion of discharge that falls outside the target area (off the ends of the sprayline or sides of the field as a whole).

SYSTEM OPERATION

Water quality

The water used for the test should be the same as that normally used for irrigation unmodified for the purpose of the test by any additional filtration, injection of chemicals or other processes unless specifically requested by the client.

NOTE:
For personal health and safety reasons, particular caution is necessary if water contains chemical treatments or biological wastes.

System pressure

1. Complete the test at normal operating pressure or as agreed by client and tester
   - Ensure the pressure is maintained during the test
   - Ensure the system is not affected by other significant system draw-offs such as other irrigation machines or dairy sheds
   - Ensure pressure measurements include lowest and highest areas.

Machine speed

2. Operate the centre pivot machine as near to 100% speed while ensuring a reasonable average application depth for accurate collector volume measurements
   - Minimise the effect of stop-start effects on distribution patterns
   - Apply sufficient volume for reliable measurements to be obtained
     (ISO recommend 15mm).

End gun

3. If the sprinkler package is designed with an end-gun, perform the test with the end gun operating. The number of sprinklers or sprayers operating should remain constant during the test
4. If desired the test may also be performed with the end gun not operating in order to evaluate the water distribution under those conditions

Corner system wetted radius

5. If desired the test may also be performed with the corner system (not) operating in order to evaluate the water distribution under those conditions

Field variability

6. If field elevation varies significantly, consider multiple radial uniformity tests.

ENVIRONMENTAL MEASUREMENTS

Wind

1. Record the direction and speed of the wind during the test period, and plot against relevant test locations on a map
    - Wind speed and direction relative to the sprayline should be monitored at intervals of not more than 15 minutes and recorded
    - Wind conditions at the time of the test should be representative of those experienced in normal operation
    - Wind speeds greater than 3m/s can have significant effects on uniformity.

NOTE:
At speeds greater than 3m/s the tester and client must understand the limitations of the test results. The uniformity test should not be used as a valid measure of the sprinkler package if the mean wind velocity exceeds 3m/s.

Evaporation

By preference, the uniformity test should be conducted during periods that minimise the effect of evaporation, such as at night or early morning or in winter months.

2. Record the time of day, estimated or measured temperature and humidity when the test is conducted
3. Record the temperature and humidity in the test zone during the test period
4. Determine evaporation rates using evaporation collectors identical to those used in uniformity testing
    - Place a control collector in a representative location upwind of the test area
    - Adjust readings for evaporation loss, following the procedures outlined inn the *Technical Glossary.*

Topography

If the field is not level, conduct the test in an area having elevation differences that are within the design specifications of the sprinkler package.

5. Measure the elevation difference and prepare a sketch of the ground surface profile along and across the test position
    - Record elevation at each tower.

FIELD OBSERVATIONS

Crop type

1. Record the site's planting history for previous season and year
2. Note crops planted in the area under examination, and stage of growth

Crop appearance

3. Observe the crop for signs of stress or growth difference. Patchiness is indicative of poor system performance
4. Measure or estimate the crop ground cover proportion

Soils

5. Dig or auger several holes within the irrigated area
6. Determine the soil texture and depth of rooting
7. Estimate or otherwise determine soil infiltration rate and soil water holding capacity
8. Assess the depth of water penetration
9. Note any soil features that indicate wetness, poor drainage or related properties and identify causes

Wheel ruts

10. Assess the presence and degree of wheel rutting in tower tracks. Note if water is running down wheel tracks
11. Note if 'boom backs' are used or if directional sprayers are installed either side of the tower

Ponding

12. Assess the amount of ponding particularly toward the end of the pivot where application intensity is highest
13. Note if water is ponding, running over the ground, or causing soil movement.
14. Estimate the percentage of water lost

Runoff

15. Assess the amount of runoff from the irrigated area as a result of irrigation. Only consider volumes leaving the irrigated area.

SYSTEM CHECKS

Water supply

1. Complete checks of the water supply including pumping system and mainline as specified in *Part B: Compliance and Water Supply Checklists*

Filtration

2. Check filters and note nature and degree of contamination or blockage
3. Identify when the filter was last checked or cleaned.
4. Identify if automatic cleaning or back-flushing is fitted and operational
5. Check for presence of contaminants in lines: sand, bacteria/algae, precipitates etc

System leakages

6. Visually check (as possible) headworks, mainline and the distribution system to identify any leakages or other losses from the system
7. Assess scale of leakages if any

Sprinklers

8. Record the nozzle type and orifice(s) fitted
   - Verify that the sprinkler package matches the design specifications.
9. Measure sprinkler spacing along the sprayline
10. Measure sprinkler height above canopy
11. Check sprinklers are operating and set correctly (to horizontal)
12. Randomly select at least 12 sprinklers along the length of the machine
    - Inspect them for blockages and record the cause of any blockages found
    - Assess orifice wear with a gauge tool or drill bit.

Pressure regulators

13. Randomly select several pressure regulators along the length of the machine and assess for cause and degree of blockages
    - This may require dismantling the units.

Normal speed (S_N)

14. Determine the typical time required to make one full-circle pass during periods of peak water use
    - This may be from farmer information or design specifications.

Test speed (S_T)

15. Measure the machine speed at 2/3rds effective radius – the centre point for mass discharge of the machine
    - This greatly simplifies comparisons between total machine flow and measured application depths from uniformity measurements.
16. Measure the machine test speed at the end tower
    - Time how long it takes the machine to pass over the test track, and all intermediate start and stop times.

SYSTEM FLOW

Total system flow

1. Record the water flow rate as measured by a fitted water meter with the system operating as normal
   - Wait until flow rates stabilise (up to 15 minutes) before taking readings
   - It may be necessary to take beginning and ending meter readings over a set time period to determine flow rate
   - Record flow with end gun operating and not operating.

Energy use

2. Obtain energy consumption data for the period covered by flow measurement
   - Enables calculation of irrigation energy costs.

SYSTEM PRESSURE

Headworks pressures

1. Measure pump discharge pressure
2. Measure mainline pressure after filters and control valves

Optionally measure:

3. Filter head loss
4. Pump control valve head loss
5. Throttled manual valve head loss

Pivot lateral pressure

6. Measure lateral pressures upstream of any sprinkler pressure regulators:
   - At the first available pressure test point or outlet downstream of the elbow or tee at the top of the inlet structure
   - At the last outlet or end of the pipeline. If an end-gun with booster pump is fitted, ensure the pressure reading is taken upstream of the pump
   - If pressure is read at a sprinkler, use a pressure gauge with a pitot attachment. Depending on sprinkler design, this may require dismantling the units
   - Lateral pressures cannot be inferred from readings at the sprinkler if pressure regulators are installed.

Sprinkler pressure (pressure regulator function)

7. Measure pressures of eight sprinklers using a pitot tube or in-line gauge downstream of any pressure regulator
   - First sprinkler
   - Last sprinkler (before end-gun)
   - Highest sprinkler
   - Lowest sprinkler
   - Four other sprinklers randomly along the lateral.

NOTE: This may require dismantling of the sprinkler unit to fit a temporary test point, or for access to the nozzle jet-stream.

SPRINKLER PERFORMANCE

For a centre pivot, the only direct measurement of uniformity that conforms to international conventions for uniformity testing comes from catch can collectors. The wide variety of sprinkler spacings and flow rates used in pivots (and linears) require more detailed direct testing and analysis to determine they are functioning correctly. That can be time consuming and expensive but could be a useful supplement to uniformity measurement.

Radial uniformity test

The radial uniformity test is of primary importance as it establishes variation along the length of the pivot lateral. Performance is dependent on sprinkler package design and installation, field elevation and wind or other disturbances.

The easiest location for this test is along the pivot access track, provided that area is representative of the field.

Collector placement

1. Arrange two rows of collectors either side of a radial line starting 20% of the way along the machine
   - The inner span represents a small proportion of irrigated area and flow rates are very low.

NOTE: Machines < 450m effective length:
Use a total of 80 collectors staggered to ensure the spacing between cans does not match sprinkler spacing. Arrange 40 collectors spaced up to 10m apart in each row.

NOTE: Machines > 450m effective length:
Increase the number of collectors proportionally so mean collector spacing is about 5m.

NOTE:
If an end-gun is used, the rows of collectors should be extended to just inside the wetted radius.

NOTE:
Position collectors ahead of the irrigator, at a distance more than the wetting radius of the sprinklers so the machine is operating normally when the first water reaches the collectors.

NOTE:
Do not place collectors in wheel tracks

2. Measure and record the position of each collector relative to the pivot centre
   - Rows should be 3m apart at the inner-most collector (Figure 2.1).

Wetted radius

3. Determine the average wetted width of the sprayline (sprinkler wetted radius) to the nearest 10cm in at least three locations.

Water collection

NOTE:
Collection and measurement can begin at the outer collector in the first wetted row, then progress in to the centre and back out again. This allows collection to begin as soon as possible, and while the last collector in the second row is still being wetted.

OPTIONAL TESTS

Circular uniformity test

The Circular Uniformity test recommendation is not recommended in these protocols. Much variability will be due to radial (along the pivot length) variation rather than around the circle. Effort is better used checking machine speed and pressure or repeating radial uniformity tests at different positions in the field.

Travel speed and pressure tests

Monitoring machine travel speeds and sprinkler pressures can provide useful information about machine performance and variability.

If the machine has sprinkler pressure regulators fitted and pressure is sufficient at all locations, flows should remain uniform. If travel speeds are also uniform around the circle, distribution uniformity should be constant unless sprinkler heights vary due to undulating topography.

Repeat tests

Repeat tests to determine distribution uniformity with and without the end-gun operating, or with the pivot lateral in a different field location or locations. In particular, consider up slope regions where machine pressures may be reduced.

If sprinkler heights or system pressures vary, additional radial uniformity tests will give most reliable uniformity assessments.

3.2 Data analysis

SYSTEM

Irrigated area

1. Calculate the irrigated area of the machine
   - For Full Circle machine
     Irrigated Area = Pi x Machine Length (radius)^2
   - For part Circle machine
     Irrigated Area = Pi x Machine Length (radius)^2 x (angle irrigated / 360)
   - For Circle machine with unirrigated centre zone
     Irrigated Area = Pi x Machine Length (radius)^2 – Pi x Unirrigated Inner Length^2.
2. Calculate the total area irrigated (Towable machines)
   - Total Area = Sum of individual irrigated areas.

PERFORMANCE INDICATORS

Water supply

1. Complete calculations of water supply including pumping system and mainline as specified in *Part B: Compliance and Water Supply Checklists*

Application depth

NOTE:
To make valid assessments of pivot performance, the depths measured by collectors must be weighted according to distance from the pivot centre. This accounts for the greater field area represented by collectors more distant from the pivot centre.

NOTE:
Make adjustments to account for evaporation losses.

2. Calculate Distance Adjusted Applied Volume (V_a)
3. Calculate Distance Adjusted Applied Depth (AD_{DAdj})
4. Determine the minimum and maximum distance adjusted application depths

Total machine flow application depth

5. Calculate application depth based on total machine flow, event duration and irrigated area

Application intensity

Application Intensity varies along the length of a centre pivot machine, as speeds are higher at greater radii.

6. Calculate Instantaneous Application Intensity at 2/3rd effective radius
7. Calculate Instantaneous Application Intensity at the end of the pivot
8. Calculate Instantaneous Application Intensity at the end of the effective radius if using a gun or corner arm

NOTE:
The average application rate occurs at approximately 2/3rd the full radius. Half the total machine flow is discharged in the first 2/3rd and the remainder in the outer 1/3rd.

9. Compare Application Intensities to Soil Infiltration Rate
   - Report as a percentage
   - Application Intensity should be less than Soil Infiltration Rate
   - Compare with observations of surface ponding.

DISTRIBUTION UNIFORMITY

System uniformity

Distribution uniformity is determined using the low quarter distribution uniformity coefficient, DU_{lq}.

NOTE:
Because the lowest quarter relates to a proportion of total field area, calculations must be made to determine which collectors are representing the lowest quarter.

NOTE:
Determining global 'field uniformity' requires adjustments to account for contributing factors, including distribution pattern, off-target application and run-off.

Radial uniformity coefficient, CU_R

1. Calculate the Uniformity Coefficient using the Heermann and Hein modified formula
   - This adjusts for the relative area represented by each collector.

Radial distribution uniformity, $R_{AD}DU_{LQ}$

2. Determine radial low quarter distribution uniformity from evaporation adjusted collector depths using the Distance adjusted DU_{lq}

Field distribution uniformity, FDU_{LQ}

3. Estimate overall field distribution uniformity (FDU_{lq}).

NOTE:
If system pressure is adequate at all points, and machine speed is uniform, the radial DU value will suffice.

NOTE:
If multiple radial test uniformities are included, all depths must be pooled, and a new uniformity calculation performed with the pooled data.

PRESSURE VARIATION

Mainline pressures

For towable centre pivots:

1. Calculate the percentage pressure variation between hydrants

Lateral pressure loss

2. 2. Calculate lateral pressure loss HL
   - HL = $P_{first} - P_{last}$
   - P_{first} is the pressure before the first sprinkler and P_{last} is the pressure before the last sprinkler (excluding the end-gun)

NOTE:
As a general rule, total friction loss in the pivot lateral of a 400m system on flat to moderately sloping ground should not exceed 70kPa

3. Check minimum pipeline pressure is at least 20kPa higher than the pressure regulator setting.

Pressure regulators

Pressure regulators have performance variability of about 6%. They are only recommended where pressure changes due to changes in elevation, end-gun operation or pumping lift exceed regulator variability by an amount that varies with design pressure.

In general terms, regulators are recommended if design pressure (P_d) is less than pressure variation due to elevation, pumping or end-gun operation (P_v) as given by the equation:

Fit regulators if: $P_d < (3.5\ P_v) + 3.5$

Sprinkler pressures

4. Determine mean pressure from measurements
5. Identify any sprinklers where pressure is more than 10% different to the mean pressure.

3.3 Adjust irrigation system settings

APPLIED DEPTH

1. Compare Mean Set Applied Depths to Target Depth
   - Adjust set run time to achieve target applied depth

Adjusted machine speed

2. Calculate Adjusted Machine Speed
   - Adjusted Machine Speed (m/h) = Machine Test Speed (m/h) x (Target Depth / Distance Adjusted Applied Depth) ÷ DU_{lq}

   NOTE: Including DU_{lq} ensures the Run Time applies sufficient water to adequately irrigate 7/8th plants.

Distribution uniformity

3. Identify impact of variables contributing to non-uniformity
   - Repeat Operational Checks (Section 1)
   - Adjust system components to achieve best performance
   - Ensure system is at recommended operating pressure
   - Get professional assistance.

Appendices

PART H: Pivot

Appendix 1: Centre pivot case study

A centre pivot was tested as part of system commissioning and found to have lower than expected performance. The primary causes were incorrect system pressure and nozzle selection at the machine towers. The problems were increased by field topography. Additional problems were indicated. Correcting the pressure will improve performance. Replacing half-circle nozzles at towers would enable very high uniformity to be achieved.

SYSTEM INFORMATION

The towable centre pivot irrigator operates over two river terraces 25m above the river. Water is pumped from a river bed gallery to the pivot via a variable speed drive pump. A steep terrace scarp intersects the circle. The lowest part of the 60ha irrigated area is 5m below the pivot centre and the highest 10m above.

The 407m, 8 span machine is fitted with 24 pressure regulated spinner sprinklers per span and an end gun giving an overall effective length of 430m.

The machine has closely spaced sprinklers set at 2m above flat ground. While crossing the terrace edge the sprinklers were much lower, including one area where they dragged on the ground. Pressure regulators set pressure to 70kPa. Directional sprinklers either side of each tower keep water of the wheel tracks.

Machine speed, pump performance, sprinkler performance, catch-can and system pressure measurements were taken while the machine was irrigating a sector including the top terrace.

METHODOLOGY

The test was undertaken with the machine in the highest section of the irrigated area. This is the most severe test, where pressure is most likely to be limiting.

Catch cans were laid out in two radial rows as specified in the Evaluation section of the Performance Assessment Code. The rows started after the first tower and extended to the edge of the area wetted by the end-gun.

The machine was run across the catch cans at 75% of full speed and the speed measured. The volume of water collected was measured and the applied depth determined. Pressure was measured above the pressure regulators before the last tower, away from interference by the end-gun pump.

RESULT SUMMARY

For testing, the machine was operated at 75% speed which would enable it to complete one revolution in 10.7 hours. With a rapid shift, this would just enable two circles to be irrigated per day.

The end-gun was not reaching the boundary fence that had been erected around the circle.

Table 1

Indicator	Actual	Recommended
Water meter flow	78.3L/s	
Pump discharge pressure	1,180kPa	
Pressure at the pivot centre	200kPa	
Pressure at pivot end sprinkler	75kPa	110kPa+
Target Depth		6.0mm
Measured Depth	4.7mm	
Distribution Uniformity	0.75	0.85+
Christiansen Uniformity	0.84	0.90+
Application Intensity 2/3rd radius	100mm/h	<70mm/h
Application Intensity end tower	126mm/h	<70mm/h

APPLICATION DATA

System pressure readings showed the Variable Speed Drive had been set low to save energy costs, but too low for correct pressure regulator function. Pressure above the regulator should typically be 40kPa higher than the regulated pressure to ensure correct functioning.

The mean applied depth along the machine was 4.7mm, with a range of 1.8mm to 7.2mm. This was less than the 6mm target depth.

The Low quartile Distribution Uniformity (DU_{lq}) was 0.72 which is poor for a centre pivot.

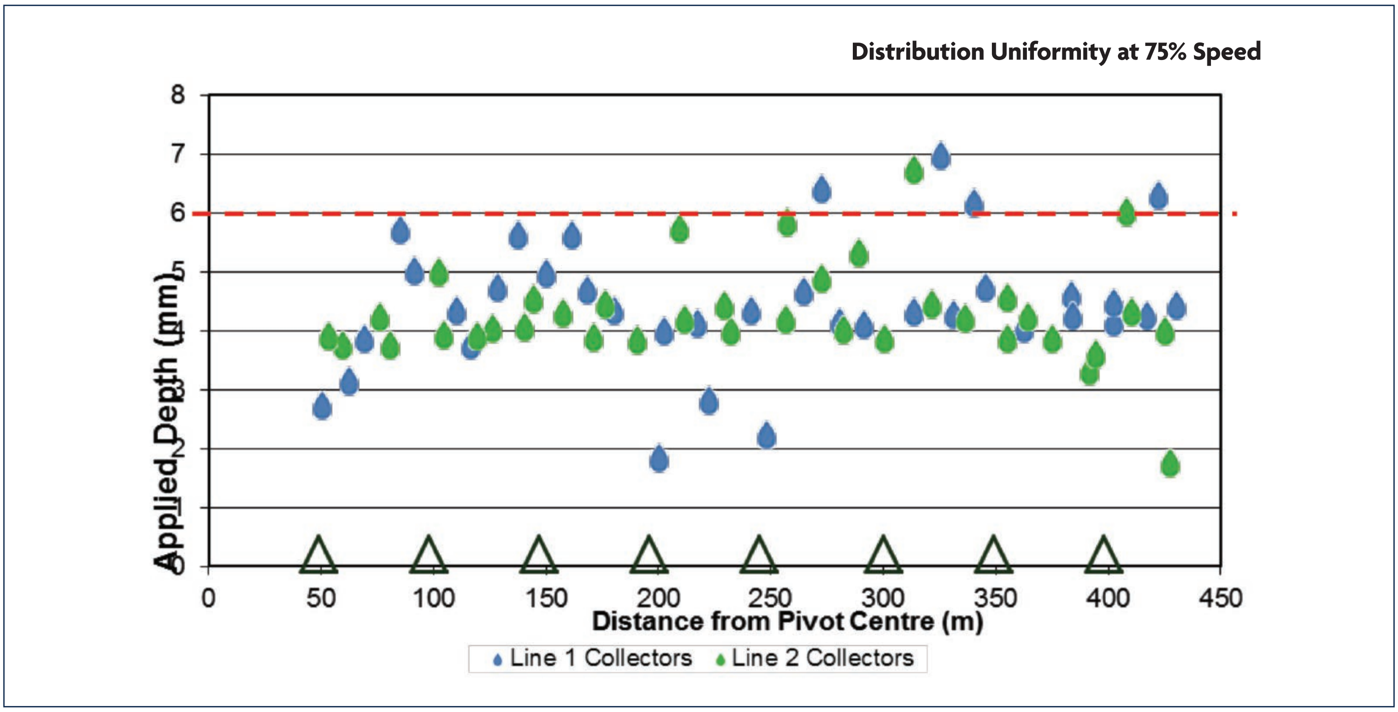

Figure 1. The recorded Irrigation Applied Depths along Centre Pivot starting from the centre (0) moving outwards. The elevation of each tower is also shown with the triangles. Red line denotes target depth.

The major reason for poor performance is sprinkler choice. The data collected from catch cans indicate an issue at the towers (Figure 1) which is where fixed half-circle sprays are fitted. When data from all spans are overlaid and graphed the effect of this is clearly seen (Figure 2).

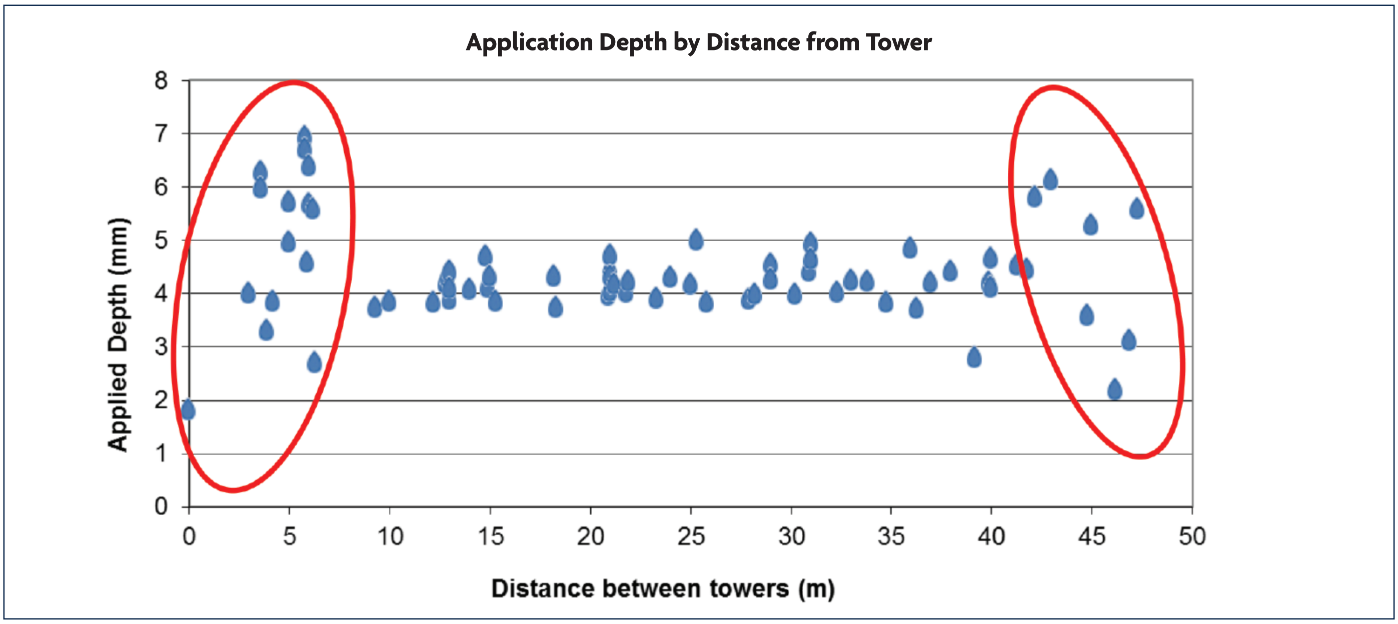

Figure 2. Application depth with all spans overlaid – catch can measurements relative to distance from towers.

Figure 2 shows that in the mid-section of the pivot spans the applied depth is very uniform (DU_{lq} = 0.96). However there is wide spread at the towers as indicated by the red rings in Figure 2. Investigation showed this was caused by half circle sprays directing water away from the wheel tracks shown in Figure 3.

Figure 3. Half-circle sprays direct water away from pivot tower.

Figure 4. Very steep areas exacerbate surface run-off and apply high loads to machine components including gearboxes.

The use of half-circle sprays did keep water off the tracks but also created a band almost 7m wide at every tower where irrigation was under-applied (the red zone in Figure 3). Outside that was an area where excessive application was made (the blue zone in Figure 3). Altogether along the total length of the pivot, the half-circle sprays left almost a quarter of the area incorrectly irrigated.

OTHER ISSUES TO MONITOR

Ponding and run-off

The Irrigation Design Code of Practice recommends maximum Application Intensities on sandy loam soils of 20mm/hour (slope 0–8˚), 17mm/hour (slope 9–12.5˚) and 13mm/hour (slope over 12.5˚). While some of the irrigated area is within the 0–8˚ limit, some is significantly greater.

Because a drier soil can accept water somewhat faster, application intensities can be about three times the stated intensity. While on flat areas, this machine may be able to apply at about 70mm/hour with minimal ponding and run-off. The steeper areas should still be kept below about 40mm/hour to avoid losses.

The application intensity of the machine is very high (100mm/h at 2/3rd radius) so ponding and run-off can be assumed particularly on sloping areas. At the end of the machine this problem is even greater.

Machine wear

The machine is operating on steep terrain with harsh angles at tower pipe joints. The wheels were observed to slip on steeper sections, leaving gearboxes subject to heavy loads. Strategic ground contouring can lessen these problems.

Sprinkler damage

Some sprinklers were damaged even though the machine was very new. They main cause was from being dragged along the ground as the spans passed over the terrace edge (Figure 5).

Figure 5.

RECOMMENDATIONS

Pressure

The pumping pressure was increased after a first test. This ensured pressure regulators would have satisfactory intake pressure along the machine to the end sprinklers.

Sprinkler selection

The rotators fitted along the machine performed very well. The half-circle sprays fitted at the towers caused major problems and should be replaced.

Replacing the half-circle sprays with standard spinners or rotators would give greatly improved application uniformity and increased irrigation effectiveness and efficiency. Water running down the towers into wheel tracks should not be excessive. A cautionary alternative would fit spinners to boom-backs so the machine has passed over the track before water is applied.

An interim measure would be turning the half-circle sprays to about 45° so they apply water after the wheels have passed. This would more evenly to the strips either side of the tower.

Ground shaping

Ground shaping areas to mediate grade where the towers climb very steeply would reduce the load on gearboxes and other structural parts. This would prevent early failure. Correctly designed, this would also elevate the mid-span sections so the sprinklers were off the ground, avoiding damage and improving application uniformity.