## 4.7 Field evaluation of centre pivot irrigation machines

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## 4.7.1 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.

Centre pivot irrigation machines are used on over half the sprinkler irrigated land in the United States (CPD) and increasingly in New Zealand. They make irrigation feasible in many areas where other techniques are not suitable. 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.

### 4.7.1.1 This Schedule

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.

## 4.7.2 Special features for analysis

### 4.7.2.1 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 *rate* must increase further out along the lateral to give the same application *depth*.

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

### 4.7.2.2 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 (CPD, TAE).

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.

#### 4.7.2.3 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.

### 4.7.3 Technical materials

#### 4.7.3.1 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*

#### 4.7.3.2 Technical references

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

Anon. 2001. *The New Zealand Irrigation Manual: A practical guide to profitable and sustainable irrigation.* Malvern Landcare/Environment Canterbury. Canterbury, New Zealand. (NZI)

New, L. and G. Fipps. 2002. *Center Pivot Irrigation.* Bulletin B-6096. 4.00. Texas Agricultural Extension Service. The Texas A&M University System. via internet: http://amarillo.tamu.edu/amaweb/Programs/EnviroSys-NatRes/IrrigaWtrQlty/publications/B-6096-CtrPivIrri.pdf

#### 4.7.3.3 Abbreviations

Reference abbreviations used in text

| | |
|---|---|
| Cal | Burt, Walker, Styles and Parrish. 2000 |
| CPD | Allen, Keller and Martin. 2001 |
| IEP | Buttrose and Skewes. 1998 |
| ISO | ISO 11545:2001 |
| NZI | Anon. 2001 |
| TAE | New and Fipps. 2002 |

#### 4.7.3.4 Related schedules and appendices

| | |
|---|---|
| Section 2 | Conducting a field evaluation |
| Schedule 3 | Seasonal irrigation efficiency assessment |
| Schedule 4.6 | Linear move irrigator evaluation |

Appendix **Error! Reference source not found. Error! Reference source not found.**

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## 4.7.4 Test procedures

This schedule outlines procedures to be followed when assessing distribution uniformity of a centre pivot irrigation machine as a 'snapshot exercise' under prevailing field conditions. To gain most benefit, conditions at the time of the test should be representative of those experienced in normal operation.

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

## 4.7.5 Test site

### 4.7.5.1 Location

If the irrigation site is level, the easiest location for the test is usually along an access track.

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.

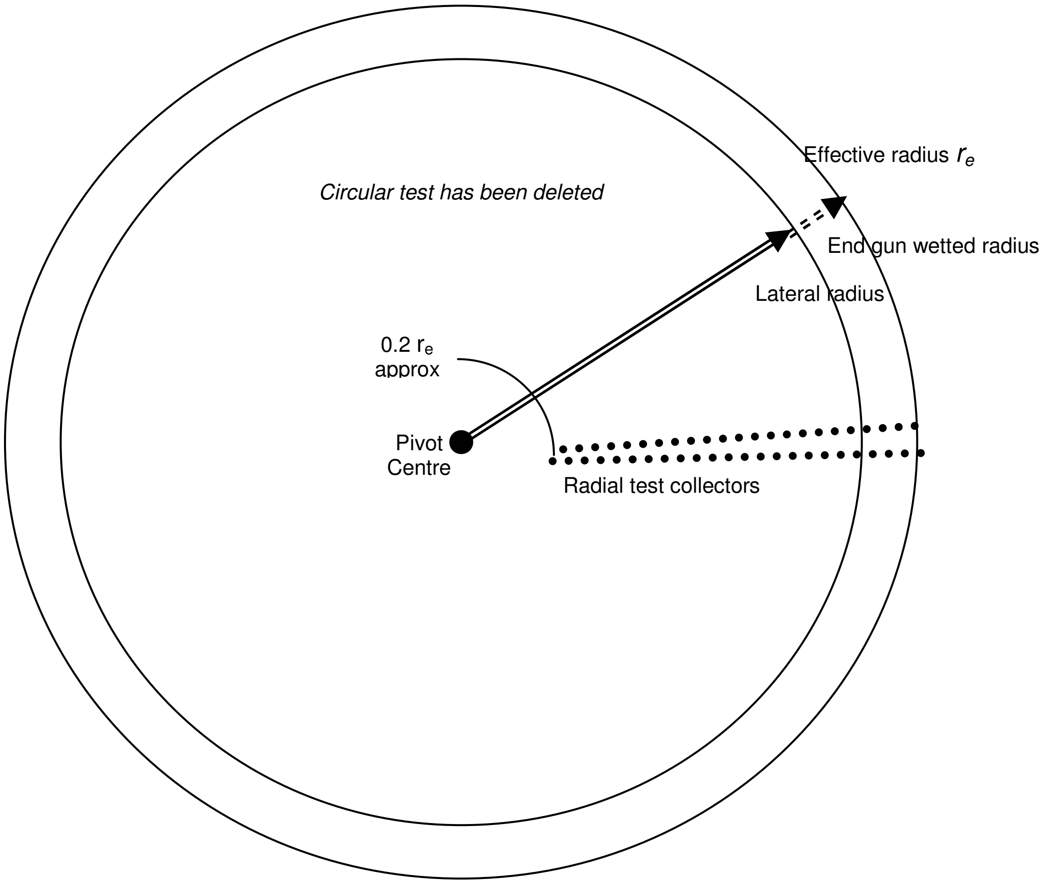


**Fig 4.7.1. Layout for pivot uniformity tests**

### 4.7.5.2 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.

## 4.7.6 System survey

### 4.7.6.1 System layout

Prepare a map of the system recording the headworks, mainline, take-off points, sub-mains, manifolds and laterals. Mark positions where tests are to be conducted (see examples **Error! Reference source not found.** and Fig 4.7.1).

### 4.7.6.2 Machine length

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

### 4.7.6.3 Un-irrigated length

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

### 4.7.6.4 End gun wetted radius

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

### 4.7.6.5 Effective radius (re)

Measure the effective radius from pivot centre (Fig 4.7.1).

### 4.7.6.6 Corner system wetted radius

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

## 4.7.7 System operation

### 4.7.7.1 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 (FDIS).

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

### 4.7.7.2 Pressure

Standard tests should be run at the normal operating pressure, or as mutually agreed upon by client and tester. Ensure the pressure is maintained during the test (~ISO).

- To maintain constant pressure, ensure the system is not affected by other significant system draw-offs such as other irrigation machines or dairy sheds.

### 4.7.7.3 Machine speed

The machine speed selected for the test should minimise the effect of stop-start effects on distribution patterns from any one-off test, and apply sufficient volume for reliable measurements to be obtained.

Operate the centre pivot machine as near to 100% speed (Cal) while ensuring a reasonable average application depth for accurate collector volume measurements (ISO recommend 15mm).

### 4.7.7.4 End gun

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.

If desired the test may also be performed with the end gun not operating in order to evaluate the water distribution under those conditions (ISO)

#### 4.7.7.5 Corner system wetted radius

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

#### 4.7.7.6 Field variability

If field elevation varies significantly, consider multiple tests to increase accuracy of distribution uniformity assessments. This may involve several radial uniformity tests.

### 4.7.8 Environmental measurements

#### 4.7.8.1 Wind

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 (ISO).

Wind conditions at the time of the test should represent those of normal operation.

Wind speeds greater than 3 m/s can have significant effects on uniformity and the tester and client must understand the limitations of any test results. The uniformity test should not be used as a valid measure of the sprinkler package if the wind velocity exceeds 3 m/s (ISO).

#### 4.7.8.2 Evaporation

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.

Record the time of day, estimated or measured temperature and humidity when the test is conducted (ISO, Cal, IEP).

Record the temperature and humidity in the test zone during the test period.

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 in Appendix **Error! Reference source not found. Error! Reference source not found.**

#### 4.7.8.3 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.

Measure the elevation difference and prepare a sketch of the ground surface profile along and across the sprayline (~ISO).

If the field is not level, measure the profile along and across the sprayline. Include a sketch of the profile along each line of collectors with the results unless the ground surface is level.

### 4.7.9 Field observations

#### 4.7.9.1 Crop type

Record the field's planting history for previous season and year.

Note crops planted in the area under examination, and stage of growth.

#### 4.7.9.2 Crop appearance

Observe the crop for signs of stress or growth difference. Banding, striping or patchiness is indicative of poor system performance.

Measure or estimate the crop ground cover proportion.

#### 4.7.9.3 Soil appearance

Dig, or auger, several holes within the irrigated area.

Assess the level of water penetration at each site and record. Note any soil features that indicate wetness, poor drainage or related properties and identify causes.

#### 4.7.9.4 Soil properties

Determine the soil texture and depth of rooting.

Estimate or otherwise determine soil infiltration rate and soil water holding capacity.

#### 4.7.9.5 Wheel ruts

Assess the presence and degree of wheel rutting in tower tracks. Note if water is running down wheel tracks (Cal, IEP).

Note if ‘boom backs’ are used or if directional sprayers are installed either side of the tower.

#### 4.7.9.6 Ponding

Assess the amount of ponding particularly toward the end of the pivot where application rates are highest. Also check the centre where machine speeds are lowest. Note if water is ponding, running over the ground, or causing soil movement. Ponding can significantly reduce application uniformity in a field.

#### 4.7.9.7 Runoff

Assess the amount of runoff from the irrigated area as a result of irrigation. Only consider volumes leaving the irrigated area and not recaptured for re-use. Runoff does not affect uniformity, but does reduce irrigation efficiency.

### 4.7.10 System checks

#### 4.7.10.1 Filtration

Check filters and note nature and degree of contamination or blockage (Cal, IEP).

Identify when the filter was last checked or cleaned. Identify if automatic cleaning or back-flushing is fitted and operational.

#### 4.7.10.2 System leakages

Conduct an overall visual check (as possible) of headworks, mainline, hydrants, connection lines and the distribution system to identify any leakages or other losses from the system.

#### 4.7.10.3 Sprinkler package

Before testing a system, verify that the sprinkler package has been installed according to the design specifications, unless specified otherwise by the client (ISO).

#### 4.7.10.4 Pressure regulators

Randomly select several pressure regulators along the length of the machine and remove them for assessment of blockages. This may require dismantling the units (IEP).

#### 4.7.10.5 Normal speed (Sn)

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

#### 4.7.10.6 Test speed (St)

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 (4.7.11.1) and measured application depths from uniformity measurements (4.7.15.5).

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 (IEP).

## 4.7.11 Flow measurement

### 4.7.11.1 Total machine flow

Record the water flow rate with the end-gun operating. Wait until flow rates stabilise (<15 minutes) before taking reading. It may be necessary to take beginning and ending meter readings over a set time period to determine flow rate.

If desired, record flow with end-gun off, waiting until flow stabilises before taking any reading.

## 4.7.12 Pressure measurement

### 4.7.12.1 Headworks pressures

With system operating, measure:

- Pump discharge pressure
- Mainline pressure after filters and control valves

Optionally measure:

- Filter head loss
- Pump control valve head loss
- Throttled manual valve head loss

### 4.7.12.2 Pivot lateral pressure

With the system operating, 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 (ISO, IEP, Cal).
- At the last outlet or end of the pipeline (IEP, Cal). 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 (IEP).

Lateral pressures cannot be inferred from readings at the sprinkler if pressure regulators are installed.

### 4.7.12.3 Sprinkler pressure (pressure regulator function)

Check pressures of eight sprinklers using a pitot tube or in-line gauge downstream of any pressure regulator. This may require dismantling of the sprinkler unit to fit a temporary test point, or for access to the nozzle jet-stream.

With system operating, measure pressure at

- First sprinkler
- Last sprinkler (before end-gun)
- Highest sprinkler
- Lowest sprinkler
- Four other sprinklers randomly along the lateral

## 4.7.13 Sprinkler performance

For a centre pivot with overlapping sprayers or sprinklers, the only useful measurement of uniformity comes from catch can collectors. This is because such systems have a wide variety of sprinkler spacings and flow rates and more detailed analysis will be time consuming and expensive (Cal).

### 4.7.13.1 Sprinklers/sprayers

Randomly select at least 12 sprinklers or sprayers along the length of the machine. Inspect them for blockages and record the cause of any blockages found.

Check sprinkler height above canopy meets manufacturer's recommendations (Cal).

### 4.7.13.2 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.

### 4.7.13.3 Collector placement

**Paired radius test**

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

Rows should be 3m apart at the inner-most collector (Fig 4.7.1 and Fig 4.7.2 ).

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

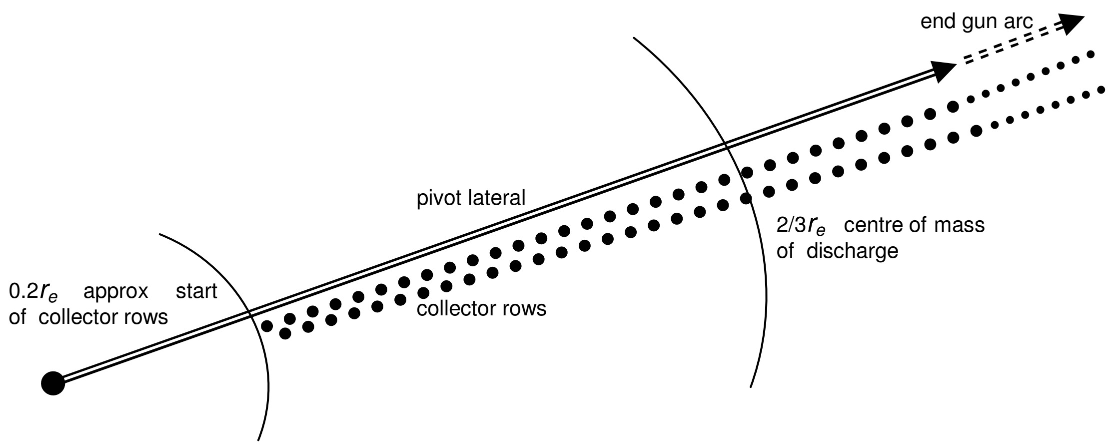


**Fig 4.7.2 Collector placement for paired radial test**

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.

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

- Measure and record the position of each collector relative to the pivot centre.
- 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. Do not place collectors in wheel tracks.

#### 4.7.13.4 Water collection – radial uniformity test

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.

## 4.7.14 Optional tests

#### 4.7.14.1 Circular uniformity test

The Circular Uniformity test recommendation has been removed from these protocols. Much variability will be due to radial (along the pivot length) variation rather than around the circle. Effort is better used repeating radial uniformity tests at different positions in the field.

#### 4.7.14.2 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.

#### 4.7.14.3 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.

## 4.7.15 Performance indicators

#### 4.7.15.1 Distribution uniformity

Distribution uniformity is determined using the low quarter distribution uniformity coefficient, $DU_{lq}$. Because the lowest quarter relates to a proportion of total field area, not total collector number, calculations must be made to determine which collectors are representing the lowest quarter.

#### 4.7.15.2 Uniformity Coefficient

If calculating statistical coefficient values, ensure modified formulae are used where, and only as, appropriate.

- **Radial uniformity coefficient (CUr)**

Calculate the Uniformity Coefficient using the modified formula of Heermann and Hein. This adjusts for the relative area represented by each collector (ISO, CPD).

#### 4.7.15.3 Application depth

To make valid assessments of pivot performance, the depths measured by collectors must be adjusted to account for evaporation losses and weighted according to distance from the pivot centre.

#### 4.7.15.4 Application rate

Application rates vary along the length of a centre pivot machine, as speeds are higher at greater radii. The average application rate occurs at approximately 2/3$^{rds}$ the full radius. Half the total machine flow is discharged in the first 2/3$^{rds}$ and the remainder in the outer 1/3$^{rd}$.

Instantaneous application rates are calculated at 2/3$^{rd}$ effective radius and at the end of the pivot. Rates are compared to soil infiltration rates providing an indication of possible surface redistribution, with subsequent impacts on uniformity.

## 4.7.16 System uniformity

### 4.7.16.1 Required adjustments

Determination of global 'field uniformity' requires that adjustments are made to account for various contributing factors, including sprinkler flow variation, distribution pattern, off target application and run-off.

Adjustments are also required to account for evaporative losses from collectors while field data collection is undertaken.

Centre pivots uniquely require a weighting to be applied to collector results. This accounts for the greater field area represented by collectors more distant from the pivot centre.

### 4.7.16.2 Field distribution uniformity, $FDU_{lq}$

Estimate overall field distribution uniformity ($FDU_{lq}$). If system pressure is adequate at all points, and machine speed is uniform, the radial DU value will suffice. If multiple collector uniformities are to be included, all depths must be pooled, and a new uniformity calculation performed with the pooled data.

Protocols for combining surface redistribution effects are, as yet, not determined.

### 4.7.16.3 Radial distribution uniformity, $RadDU_{lq}$

Determine radial low quarter distribution uniformity from evaporation adjusted collector depths using the Distance adjusted $DU_{lq}$ **Error! Reference source not found.**.

## 4.7.17 Other uniformity factors

### 4.7.17.1 Sprinkler discharge uniformity

Testing sprinklers is not viable as the performance of each necessarily varies from the rest. It is not feasible to determine desired flows without a specific analysis / design program.

### 4.7.17.2 Uniformity coefficient – radial test

Calculate the statistical uniformity coefficient for radial tests based on the Heermann-Hein modified Uniformity Co-efficient **Error! Reference source not found.**.

## 4.7.18 Application Depth

### 4.7.18.1 Required adjustments

To make valid assessments of travelling irrigator performance, the depths measured by collectors must be adjusted to account for evaporation losses and for the effect of increasing distance from pivot centre (see 4.7.16.3).

### 4.7.18.2 Evaporation adjustment

Make adjustments for evaporation losses as set out in Appendix **Error! Reference source not found. Error! Reference source not found.**.

### 4.7.18.3 Total machine flow application depth

Calculate application depth based on total machine flow, cycle duration and irrigated area using **Error! Reference source not found.**.

### 4.7.18.4 Collector application depth

Calculate the mean application depth within the radial test zone, after adjusting for evaporation and distance from pivot centre.

Calculate the minimum and maximum application depths after adjustments as above.

## 4.7.19 Application rates

The application rates under a centre pivot increase with distance form the pivot centre.

The instantaneous application rate may be calculated using the flow and area determined for the entire irrigated circle.

### 4.7.19.1 Instantaneous application rates

Calculate the maximum instantaneous application rates **Error! Reference source not found.** at:

- the centre of mass of discharge,
- the end of the lateral, and
- the end of the effective radius.

## 4.7.20 Pressure variation

### 4.7.20.1 Mainline pressures

For towable centre pivots:

Measure the available pressure at each hydrant and calculate the percentage variation.

### 4.7.20.2 Lateral pressures

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

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 (TAE).

Check that the minimum pipeline pressure is at least 20kPa (TAE) higher than the pressure regulator setting (IEP).

### 4.7.20.3 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: $P_d < (3.5\ P_v) + 3.5$

(Adapted from Allen, Keller and Martin, after Nelson Irrigation Corp 1998)

### 4.7.20.4 Sprinkler pressures

Determine mean pressure from measurements (4.7.12.3).

Identify any sprinklers where pressure is more than 10% different to the mean pressure.