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### Moving irrigation systems

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1 Introduction

The number of moving irrigation systems in use in South Africa has increased since 1970. Moving irrigation systems are, as the name indicates, machines with sprinklers or sprayers that move across a field distributing water and are opposed to systems where pipes and sprinklers are moved by hand. Refer to Chapter 10: Irrigation systems.

With moving systems management aspects are simpler, scheduling can be done more accurately and labour problems are largely reduced or eradicated. Growers are mainly persuaded to change from conventional irrigation systems to moving irrigation systems because of labour and management. Labour management and the availability of willing workers, especially in the cold seasons, are important considerations. A further advantage is that it is much easier to apply smaller amounts of water more frequently, for example 15 mm to 30 mm every 2 to 5 days. This is a high advantage with some crops in certain growth stages especially at germination on problem soils. It is also easier to apply overhead fertigation to meet crop demands.

Moving systems are mainly applicable to agronomic and gardening crops and pastures. They are not applied to orchards and fruit cultivation, as permanent systems are better suited and not much more costly.

The key to economic justification of moving systems is to utilise them maximally. At least two and if practically possible, three crops per year should be irrigated with the same system. For economic justification therefore, the system should wear down and not rust apart.

2 System types

Moving systems include all systems that move while applying water to the surface of a field.

2.1 Centre pivots

A centre pivot consists of steel frames and pipes, which are supported at approximately 50 m intervals by an A-frame on two wheels.

2.1.1 General

All centre pivots are constructed from the following basic components:

- Pivot structure
  This is used to anchor the centre pivot. The whole structure rotates around it.

- Span
  This is the basic structural unit with which a centre pivot is constructed. A unit consists of the main pipe in which the water flows, the frame, which supports the pipe and the driving mechanism. Spans are distinguished from each other based on the following variables:
Table 14.1: General centre pivot spans available

<table>
<thead>
<tr>
<th>Span length [m]</th>
<th>Pipe diameter [mm]</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>168</td>
<td>2 268</td>
</tr>
<tr>
<td>38</td>
<td>168</td>
<td>2 449</td>
</tr>
<tr>
<td>45</td>
<td>168</td>
<td>2 631</td>
</tr>
<tr>
<td>52</td>
<td>150</td>
<td>2 648</td>
</tr>
<tr>
<td>56</td>
<td>150</td>
<td>3 130</td>
</tr>
<tr>
<td>32</td>
<td>203</td>
<td>2 722</td>
</tr>
<tr>
<td>38</td>
<td>203</td>
<td>3 266</td>
</tr>
<tr>
<td>52 (corner system)</td>
<td>150</td>
<td>2 948</td>
</tr>
<tr>
<td>56 (corner system)</td>
<td>150</td>
<td>3 084</td>
</tr>
</tbody>
</table>

- Length and pipe diameter
  Any combination of pipe sizes and spans on a specific centre pivot may be identified by a model number.

- Crop clearance height
  The manufacturer can supply details of the crop clearance height of the different span lengths for a specific type of centre pivot. The designer must determine the average slope \( \frac{(a + b)}{2} \) at critical positions on a field.

Figure 14.1: Crop clearance height

- Towability
  The following restrictions apply to towable centre pivots:
  - Soil type and topography
    Guard against clay soils and cross slopes along the towing route.
  - Centre pivot length
    The maximum number of spans for a towable centre pivot must be obtained from the manufacturer.
  - Roads
    A six metre wide road with a level surface must be made to tow the centre pivot along. Take care where centre pivots have to be towed over contour mounds.
- Span combination
  Only certain span combinations may be towed. Contact the manufacturer for relevant details. Seeing that short spans are more stable than long ones, they should always be placed closest to the centre.

- Pivot flex
  Contact the manufacturer to obtain the flexibility of the coupling at the centre of the centre pivot. The coupling can only accommodate a certain percentage slope (a) between the centre and the first driving unit. The allowable slope differs for the different tower lengths and between different centre pivot models.

![Figure 14.2: Pivot flex](image)

- Overhang
  The overhang is mounted at the end of the centre pivot to irrigate an additional area.

It is very important that limitations, as set by manufacturers, for placing of the different spans with towable as well as non-towable models, be carefully considered during design and erection.

When a centre pivot is designed for a specific field, the topography of the land must be thoroughly investigated in addition to the above factors. Each centre pivot has certain slope limitations due to the structural and driving power design.

The adaptability of the system to all remaining slopes must be investigated.

![Figure 14.3: Slope limitations for centre pivots](image)
The climbing ability of a centre pivot is limited by structural requirements and driving power. Attention should be given to ascending as well as descending slopes as it may result in variations in speed. The slope absorption at the towers and torque and swivel action at the couplings must be kept within the particular manufacturer's specifications.

2.1.2 Field data required for centre pivot design

A contour map showing borders, obstructions, water source and available electrical supply points must be available for the centre pivot design.

The flow rate and constant delivery of the water source must be determined if it is unknown. Water quality must be determined and evaluated according to the norms as discussed in Chapter 5: Water.

A complete soil report giving soil types and depths, water-holding capacity and infiltration ability, must be available before planning is commenced. Chapter 3: Soil may be consulted if any problem soils are encountered.

2.1.3 The influence of the soil's infiltration ability on centre pivot design

The centre pivot design must be adapted so that the application-rate is not greater than the soil's infiltration rate. The danger of this happening is much greater at the farthest tower, where the highest application rate occurs, than for example at towers closer to the centre.

It is generally accepted that the soil's infiltration rate is influenced by various factors like soil texture, soil moisture content, density and droplet size. Field observations, however, have shown that crust forming is a determining factor. The crust is mainly formed by external energy of rain and irrigation droplets, which break down and rearrange soil particles during wetting.

The application-rate of a specific centre pivot is a fixed property. It is a function of the flow rate, machine length and the width of the sprinkler-wetting strip. With a centre pivot, the system moves around the centre anchor. For the same time interval, sprinklers on the last tower therefore have a longer travel length and also a larger area to cover than those closer to the centre. Therefore the application-rate progressively increases towards the outer sprinklers to obtain the required total even application along the centre pivot length.

![Typical infiltration curves](image_url)
Potential run-off occurs where the application rate curve lies above the infiltration curve (see Figure 14.4). Potential run-off may be limited by improved surface conditions like a covering layer and plant growth, which break the water's kinetic energy. Practical experience has shown that smaller droplets from low-pressure sprinklers provide a better infiltration than larger droplets from low-pressure sprinklers.

Land slopes and tilling practices (hollows in the land) also promote surface storage. The following guidelines may be used for typical conventional tillage under irrigation:

<table>
<thead>
<tr>
<th>Slope [%]</th>
<th>Surface storage ability [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>12,5</td>
</tr>
<tr>
<td>1 - 3</td>
<td>7,5</td>
</tr>
<tr>
<td>3 – 5</td>
<td>2,5</td>
</tr>
</tbody>
</table>

See appendix A for the infiltrometer and the interpretation of the nomogram to determine centre pivot length for a specific field.

2.1.4 Flow rate calculations

The following general equation may be used for determining flow rate:

\[
Q = \frac{A \cdot 10 \cdot \text{NIR}}{t_\text{d} \cdot t_\text{h} \cdot \eta_s}
\]  

(14.1)

where 
- \( Q \) = flow rate \([m^3/h]\)
- \( A \) = area \([ha]\)
- \( \text{NIR} \) = net irrigation requirement \([mm/day]\)
- \( t_\text{h} \) = working hours per day \([hours]\)
- \( t_\text{d} \) = working days per week \([days]\)
- \( \eta_s \) = system efficiency \([fraction]\)

The size of the area served by the centre pivot, is equal to the area effectively covered by its wetted radius during one season.

\[
A = \pi R^2
\]  

(14.2)

where \( R \) = span length + overhang + effective radius of end sprinkler

Therefore, if a centre pivot serves two circles per cycle per season (moved cycle), the area is the total area of the two circles covered. It must be ensured that the soil’s infiltration rate is not exceeded, as the application rate doubles. Therefore the soil type and sprinkler choice play a major role. In many areas it is possible to harvest twice in one season with the correct crop choice. As soon as the first crop’s demand starts decreasing, the centre pivot may be moved to the second position to begin with soil preparation.

The net irrigation requirement can be determined, using the equation as described in Chapter 4: Crop water relationships and climate.
\[
\text{NIR} = \text{ET} - \text{Re} \tag{14.3}
\]

where
- \(\text{NIR}\) = net irrigation requirement [mm/period]
- \(\text{ET}\) = evapotranspiration [mm/period]
- \(\text{Re}\) = effective rainfall [mm/period]

In determining the permissible working hours, allowance must be made for unforeseen delays during peak demand as well as moving time (± 2 hours) if the centre pivot is moved during the season (moveable cycle). It is difficult to irrigate more than three circles with one centre pivot. In this case, different crops, or the same crop with different planting dates on the different positions must be considered.

The system efficiency is chosen according to the design norms of the different areas. A general value is 85%.

**Example 14.1:**

A farmer wants to use his centre pivot to irrigate two 20 ha circles per cycle. With the aid of equations in Chapter 11: Planning, the net irrigation requirement is 8 mm/day and a cycle length of 10 days must be maintained. Twenty-two working hours per day are available for a 7-day working week.

**Solution:**

From equation 14.1:

\[
Q = \frac{A \times 10 \times \text{NIR} \times 7}{t_h \times t_s \times \eta_s} = \frac{(2 \times 20) \times 10 \times 8 \times 7}{22 \times 7 \times 0.85} = 171.1 \text{ m}^3 / \text{h}
\]

**2.1.5 Application per cycle**

The total application of a centre pivot is the amount of water applied to a field when the centre pivot has completed one rotation. The application is altered by changing the travel speed of the centre pivot.

The rotation time \(t\) at 100% speed setting can therefore be determined as follows:

\[
t = \frac{2 \pi r}{60v} = \frac{0.1047 \times r}{v} \tag{14.4}
\]

where
- \(t\) = rotation time at 100% speed setting [hours]
- \(r\) = distance from centre to farthest driving wheel [m]
- \(v\) = travel speed of farthest wheel at 100% speed setting [m/min]
From equation 14.1 the gross application per rotation may be determined as follows:

\[ GA = \frac{Q \cdot t}{10 \cdot A} \quad (14.5) \]

where
- \( GA \) = gross application at 100% speed setting [mm]
- \( Q \) = centre pivot flow rate [m³/h]
- \( t \) = rotation time at 100% speed setting [hours]
- \( A \) = area [ha]

A schedule of the amount of gross application at different percentage speed settings of the centre pivot may now be compiled.

\[ t_v = \frac{t}{v_v} \quad (14.6) \]

where
- \( t_v \) = rotation time at a specific % speed setting [hours]
- \( v_v \) = specific speed setting [fraction]

This equation may only be used for the initial estimate during design. Variations may occur due to factors beyond the designer's control, e.g. soil conditions, wheel slippage and pivot pressure. A more accurate schedule can only be compiled after installation using physical field readings.

The following values may be used in determining rotation times and application depths.

*Table 14.3: Wheels and motors available for centre pivots*

<table>
<thead>
<tr>
<th>Type of drive</th>
<th>Motor speed (rpm)</th>
<th>Speed (m/min) for different wheel sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>11,2&quot; x 24&quot;</td>
</tr>
<tr>
<td>Worm</td>
<td>25</td>
<td>1,55</td>
</tr>
<tr>
<td>Worm</td>
<td>47</td>
<td>2,89</td>
</tr>
<tr>
<td>Helical</td>
<td>28</td>
<td>1,76</td>
</tr>
<tr>
<td>Helical</td>
<td>56</td>
<td>3,51</td>
</tr>
</tbody>
</table>

Tyre pressure is very important in ensuring system efficiency and should be checked at least 3 times during the irrigation season. Low tyre pressure could result in damage to the tyres and the drive mechanism.
The manufacturer may be consulted for the correct wheel size for a given centre pivot and land slope. The following guide may be used:

- Sandy soils: $11.2 \times 24$
- Heavier soils (> 6% clay): $13.6 \times 24$ (cash crops)
  $14.9 \times 24$ (perennials)

**Example 14.2:**

Determine the rotation time and gross application at 50% speed setting for the following case:

- Centre pivot length: 308.3 m
- Distance to farthest wheel: 282.8 m
- Centre pivot flow rate: 101 m$^3$/h
- Motor speed from manufacturer's brochure: 1.64 m/min
- Permissible wheel slippage: 3%

**Solution:**

$$\text{Driving speed} = 1.64 \times \left(1 - \frac{3}{100}\right) = 1.59 \text{ m/min}$$

*From equation 14.4:*

$$\text{Rotation time} = \frac{0.104 \times 7 \times r}{v} = \frac{0.104 \times 7 \times 282.8}{1.59} = 18.6 \text{ hours}$$

*From equation 14.2:*

$$\text{Area} = \pi R^2 \approx \pi \times 308.3^2 = 29.85 \text{ ha}$$

*From equation 14.5:*

$$\text{Gross application} = \frac{Q_t}{10 A} = \frac{101 \times 18.6}{10 \times 29.85} = 6.3 \text{ mm}$$

*At 50% speed setting:*

*From equation 14.6:*

$$t_s = \frac{18.6}{0.5} = 37.2 \text{ hours}$$

$$G_A = \frac{6.3}{0.5} = 12.6 \text{ mm}$$

Similar calculations may be done for any other required speed setting.

**2.1.6 Choice of sprinkler package**
The choice of a package determines the application rate of a centre pivot. As previously mentioned in Section 2.1.3, the centre pivot application rate must not exceed the infiltration rate of the soil.

Ultra-low pressure sprinklers were developed during the late eighties. This development, however, brought about its own unique problems, the most important problem being the high application-rate which, together with a narrow wetted strip, limits the centre pivot length due to the soil's infiltration ability being exceeded. If, however, the sprinklers are mounted on a boom, the wetted strip widens, thus lowering the application rate.

An irrigation boom package usually consists of a combination of hanging pipes over the first section of the machine, followed by 7 m (24') booms over the remaining part. With long centre pivots having high flow rates, 14 m (48') booms may also be mounted on the last few towers, for example:

![Diagram of a centre pivot with hanging pipes and booms](figure1.png)

**Figure 14.5: Mounting of hanging pipes, 7m and 14m booms on a centre pivot**

The purpose of irrigation booms, lengthening progressively with centre pivot length, is to lower the application rate towards the end.

The following equation may be used to determine the average gross application rate at any position under a centre pivot:

\[ \text{GAR} = \frac{2000 \cdot Q \cdot r}{R^2 \cdot B} \]  

(14.7)

where

- \( \text{GAR} \) = average gross application rate [mm/h]
- \( Q \) = centre pivot flow rate [m³/h]
- \( r \) = radius to a fixed point [m]
- \( R \) = total centre pivot radius [m]
- \( B \) = wetted sprinkler strip width [m]

![Diagram illustrating the variables in the equation](figure2.png)

**Figure 14.6: Determination of the average application rate under a centre pivot**
The gross application rate of a specific sprinkler can be determined as follows:

\[
\text{GAR} = \frac{1000q_e}{L_e B}
\]  
(14.8)

where \(\text{GAR} = \) average gross application rate [mm/h]  
\(q_e = \) sprinkler delivery [m\(^3\)/h]  
\(L_e = \) sprinkler spacing [m]  
\(B = \) sprinkler wetted strip width [m]

Combining 14.7 and 14.8, the following equation is produced which indicates the flow rate for a sprinkler on a centre pivot:

\[
q_e = \frac{2Q r L_e}{R^2}
\]  
(14.9)

Similarly the flow rate of the big gun may be determined by adapting the above equation

\[
q_e = \frac{2Q r r_e}{R^2}
\]  
(14.10)

where \(r_e = \) effective wetted radius of end sprinkler [m]

The following procedure may be used to determine the number of each type of sprinkler boom on a specific centre pivot:

i) Determine gross application rate at the end of the centre pivot. Try to keep it lower than the soil's infiltration rate. Use a 7 m (24') boom at the first attempt. If the gross application-rate exceeds the infiltration rate, use a 14 m (48') boom and recalculate the gross application-rate with the aid of equation 14.7.

ii) Decide if a 7 m or 14 m boom is to be used.

iii) Assuming 14 m booms are chosen for the outer end of the centre pivot:

   Determine the transition point between 7 m and 14 m booms. Use the GAR value from the calculation in (i) and determine the radius where the same value can be obtained with a 7 m boom from equation 14.7.

iv) Determine the transition point between hanging pipes and 7 m booms. Repeat the steps in (ii) using \(B = \) wetted strip width of hanging pipes.

v) The radii determined in (iii) and (iv) are the maximum distances to which hanging pipes and 7 m booms may be mounted.

vi) Round off distances to nearest tower and determine the number of towers to be equipped with different booms.

vii) If it was decided that 7 m booms are sufficient in step (ii), the remaining calculations are the same except that (iii) falls away.

viii) Test the flow rates per boom to determine the discharge spacing with equation 14.9
Example 14.3:  
Determine the sprinkler package for the following centre pivot:  
Centre pivot length: 537.8 m  
Flow rate: 415 m³/h  
Span combination: 3 × 32 m + 4 × 38 m + 3 × 49 m + 2 × 56 m + 25 m O/H  
End sprinkler: None  
Wetted strip width: Hanging pipes: 9 m  
7 m booms: 17 m  
14 m booms: 29 m  
Boom spacing: 7 m boom: Every second outlet (5.18 m) if q ≤ 6.8 m³/h  
14 m boom: Every third outlet (7.77 m) if q ≤ 10.2 m³/h  

Solution:  
(i) Determine the gross application-rate at the end of the centre pivot using equation 14.7:  

\[
7 \text{ m booms} \\
GAR = \frac{2000 Q r}{R^2 B} \\
= \frac{2000 \times 415 \times 537.8}{537.8^2 \times 17} \\
= 90.8 \text{ mm/h} \\
\]

Assume the value is too high for local conditions and rather try 14 m booms.  

\[
GAR = \frac{2000 \times 415 \times 537.8}{537.8^2 \times 29} \\
= 53.2 \text{ mm/h} \\
\]

(ii) Use equation 14.7 to determine the maximum radius for 7 m booms:  

\[
r = \frac{GAR R^2 B}{2000 Q} \\
= \frac{53.2 \times 537.8^2 \times 17}{2000 \times 415} \\
= 315.2 \text{ m} \\
\]
(iii) Determine maximum radius for hanging pipes:

\[
r = \frac{53,2 \times 537,8^2 \times 9}{2000 \times 415}
= 166,9 \text{ m}
\]

(iv) Round off distances to towers (lengths according to manufacturer’s specifications)

- **Hanging pipes:** 166,9 m
- **Towers 1 - 5 (172 m)**
- **7 m booms:** (315,2 m - 172 m) = 143,2 m
- **Towers 6 - 8 (297 m)**
- **14 m booms:** Remainder of machine
- **Tower 9 - overhang**

(v) Check flow rates

**Hanging pipes:** No need to test, as a sprinkler is mounted at every outlet.

**7 m booms:**

From equation 14.9:

\[
q_e = \frac{2 Q r L_e}{R^2}
\]

Maximum radius

\[
r = \frac{q_e R^2}{2 Q L_e}
= \frac{6,8 \times 537,8^2}{2 \times 415 \times 5,18}
= 457,3 \text{ m} > 297 \text{ m}
\]

Double spacing may be used to a distance of 457,3 m, but 7 m booms may only be mounted to distance of 297 m.

\[
r = \frac{10,2 \times 537,8^2}{2 \times 415 \times 7,77}
= 457,3 \text{ m} < 537,8 \text{ m}
\]

Booms may only be mounted at every third outlet to a distance of 457,3 m, thereafter every second outlet must be used.

(vi) Number of booms

**Hanging pipes**

- **Towers 1 - 5**
  - According to manufacturer’s specification
  - **Spans:** 3 × 32 m (Outlets = 3 × 12 = 36)
  - 2 × 38 m (Outlets = 2 × 15 = 30)

**Number of hanging pipes:** 65, seeing that a pressure gauge is mounted on the first hole.
Moving irrigation systems

7 m booms

Towers 6 - 8

Spans: 2 × 38 m (Outlets = 2 × 15 = 30)
1 × 49 m (Outlets = 19)
A boom is only mounted on every second outlet.

Number of 7m booms: 25

14 m booms

Tower 9 - O/H

Spans: 2 × 49 m (Outlets = 2 × 19 = 38) (3 × spacing)
1 × 56 m (Outlets = 22) (3 × spacing)
1 × 56 m (Outlets = 22) (2 × spacing)
26 m O/H (Outlets = 10) (2 × spacing)

Number of 14 m booms = 36

2.1.7 Hydraulic calculations

The following general equations may be used to determine pivot pressure and hydrant pressure for any centre pivot:

\[ h_{\text{spil}} = h_c + h_s + h_f + h_r \]  
(14.11)

where
\( h_{\text{spil}} \) = pivot pressure [m]
\( h_c \) = sprinkler pressure (end pressure) [m]
\( h_s \) = static height to highest point [m]
\( h_f \) = friction through centre pivot [m]
\( h_r \) = friction through pressure regulator [m]

\[ h_m = h_{\text{spil}} + h_m \]  
(14.12)

where
\( h_m \) = hydrant pressure [m]
\( h_m \) = height of centre pivot [m]

- **Sprinkler pressure**
  The pressure at which the sprinklers operate (see manufacturer’s information brochure).

- **Static height**
  The height difference between the pivot and the highest point on the field. If the centre pivot is not equipped with pressure regulators, the static height differences will cause variations in sprinkler pressure and delivery. Where the end is lower than the pivot, pressure regulators may also be used to maintain a constant flow through all sprinklers.

- **Friction through pressure regulators**
  These values may be obtained from the manufacturer.

- **Friction through centre pivot**
  Friction losses are determined by, amongst others, roughness of the pipe walls, pipe diameter, flow velocity, pipe length, discharge rate and direction changes in the pipeline. Most manufacturers provide friction loss charts which indicate friction for a certain pipe diameter and length of a certain flow.
2.1.8 Safety of centre pivots

There are two safety mechanisms for centre pivot irrigation systems. With the first type the pump switches off if the centre pivot should stop and with the second type the centre pivot switches off if the pump should stop.

2.1.8.1 Switching off of pump

If the centre pivot should stop after hours, it will discharge at that position until someone switches off the pump. To prevent such over wetting conditions, a signal must be sent to the pump to switch off the moment the centre pivot stops moving.

The signal may be transmitted by one of the following methods:

- Butterfly valve method
  An electrically operated butterfly valve is installed in the pipeline at the centre pivot inlet. The valve solenoid is connected to the centre pivot's 220 V safety circuit.

  Furthermore a pressure release valve is installed near the centre pivot inlet. A pressure switch or no-flow switch may be installed at the pump.

  As soon as the centre pivot switches off, the valve solenoid is activated slowly, closing the valve. Pressure build-up in the pipe causes the pressure switch or no-flow switch to switch the pump off. The pressure release valve limits water hammer in the pipeline. Before this method is used, pipe classes, pump shut-off pressure and adjustment of release and pressure valves must be thoroughly taken into account.

- Cable method
  This method makes use of a safety cable, which directly connects the centre pivot control panel with the switchboard of an electric or diesel motor.

  The centre pivot control panel has a standard terminal connection point for a safety cable. The cable is connected in such a way, that it has a supply voltage of 24 V (AC) while the centre pivot is in operation. The pump switch must be connected to a 24 V (AC) relay (normally open). As soon as the centre pivot stops, power to the cable will be cut and the relay will switch the pump off.

  The following sizes of two-core cable may be used:

<table>
<thead>
<tr>
<th>Length</th>
<th>Cable Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shorter than 1 000 m</td>
<td>1.5 mm²</td>
</tr>
<tr>
<td>1 000 - 2 000 m</td>
<td>2.5 mm²</td>
</tr>
</tbody>
</table>

- Radio signals
  This method works on the same principle as the cable method except that the impulse from the centre pivot to the pump is given by radio signal.

  A radio transmitter is mounted at the centre pivot control panel and a receiver at the switchboard. As soon as the centre pivot switches off, a radio signal is sent to the pump, cutting the power supply.

- Siren
  If the centre pivot is operating close to a home or if it is always under supervision, a siren may be mounted on it. As soon as the centre pivot switches off, the siren warns someone who then physically switches the pump off. The siren may use 220 V or 24 V.

- Electrical safety
  This method may be used if the centre pivot and pump operate from the same
A monitor is clamped around one of the live cores of the 4-core supply cable and connected to a relay in the pump starter. Whenever the centre pivot does not draw any current for a specific period, the pump automatically switches off.

2.1.8.2 Switching off of centre pivot

If a short power failure occurs, the pump may switch off, while the centre pivot will continue to move. If this happens after hours, the centre pivot must return dry the following day, which could cause falling behind in the cycle. The general remedy is to attach a low-pressure switch to the centre pivot. As soon as the pump fails, the centre pivot pressure will drop and the system will shut down.

2.1.8.3 Low temperature safety

Temperature switches are freely available throughout the market place but should be used with great caution on centre pivots.

The problem lies therein that water does not always freeze at the same temperature. Depending on atmospheric conditions, freezing may occur at temperatures as high as 9°C. Depending on the setting on the switch it may cause the centre pivot to switch off unnecessarily or even too late.

2.1.8.4 Wind protection

In windy areas centre pivots must be anchored when not in use.

2.1.9 Power supply to centre pivots

Most centre pivots make use of a 400 V, 50 Hz power supply. Power is usually provided by an ESKOM transformer or diesel generator. Depending on the position of the power point, it is necessary in most cases to use an underground cable to supply power to the centre pivot. Four-core cables are mainly used for this purpose but sometimes three-core cables with copper earths are accepted by local authorities.

Presently power supply to centre pivots is provided in two ways, namely:

- By making use of conventional cable design where the cable is designed to meet Regulation 4.3.4 of SABS 0142-1981. Here the designer attempts to design the cable so that the maximum voltage drop under full load conditions does not exceed $\Delta V$ of 5% where 5% indicates:
  - phase to neutral: 11 volt
  - phase to phase: 19 volt
  - By making use of step-up (delta-star 400/1 000 Volt) and step-down transformers (delta-star 1 000/400 Volt). Transformers must comply with SABS 780.

It is recommended that both methods be considered during design and the most economical system chosen. Generally it will be more economical to use the conventional cable design method for smaller systems while larger systems and those with long supply cables will be more economical using transformers.
2.1.9.1 Conventional determination of cable size

The following methods may be used for determining the cable size:

Method 1:

- Determine the required current (average amps) for the particular centre pivot from Table 14.5.

- Determine the distance between the power point and the centre pivot anchor block. The required cable size can now be determined, using Table 14.6.

Method 2:

- ESPOM usually limits the maximum voltage drop ($\Delta V$) to 5% (11 volt) on the 220 V cable. Use the following equation to ensure that the underground cable size meets the requirements:

\[
\Delta V = \frac{ILF}{1000 \times \sqrt{3}}
\]

where $\Delta V = \text{voltage drop [volt]}$

$I = \text{current @ 400 Volt [amps]}$

$L = \text{cable length [m]}$

$F = \text{voltage drop factor (from Table 14.4)}$

**Table 14.4: F-factors for different cable sizes**

<table>
<thead>
<tr>
<th>Cable size [mm$^2$]</th>
<th>F [millivolt/amp-metre]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,5</td>
<td>23,2</td>
</tr>
<tr>
<td>2,5</td>
<td>13,86</td>
</tr>
<tr>
<td>4</td>
<td>8,67</td>
</tr>
<tr>
<td>6</td>
<td>5,79</td>
</tr>
<tr>
<td>10</td>
<td>3,46</td>
</tr>
<tr>
<td>16</td>
<td>2,17</td>
</tr>
<tr>
<td>25</td>
<td>1,4</td>
</tr>
<tr>
<td>35</td>
<td>1,0</td>
</tr>
<tr>
<td>50</td>
<td>0,71</td>
</tr>
<tr>
<td>70</td>
<td>0,51</td>
</tr>
<tr>
<td>95</td>
<td>0,39</td>
</tr>
</tbody>
</table>
• The transformer or generator size is given in Table 14.5. Alternatively, the following equation can be used to calculate the required kVA.

$$kVA = \frac{\sqrt{3} \times V \times I}{1000} \quad (14.14)$$

where  
kVA = kilovolt ampere required  
V = voltage (volt)  
I = average current [ampere]

**Example 14.4:**
Determine the cable size for a ten-tower centre pivot with high-speed motors. The distance from the power point to the centre pivot is 650 m.

**Solution:**

Method 1

• From Table 14.5: Average current = 16.94 amp

• From Table 14.6: Cable size = 25 mm$^2$

Method 2

Determine the required cable size, using Equation 14.13:

$$F = \frac{1000 \times \sqrt{3} \times 11}{16.94 \times 650} = 1.73$$

*From Table 14.4, a 25 mm$^2$ cable should be used.*

• Power required from Table 14.5: 12 kW (± 15 kVA for transformer)

In an alternating current circuit, reference is often made to apparent power compared to actual power. The power is the product of the voltage and the current and is indicated in volt-ampere (VA). This value does not make provision for the power factor and therefore the apparent power is always greater than the actual power in cases where the current and the circuit is not exactly in phase (see Chapter 17: Power Systems, 2.3 for calculation of the above).
Table 14.5: Electrical requirements for centre pivots without corner system

<table>
<thead>
<tr>
<th>Number of centre pivot towers</th>
<th>Standard speed motor</th>
<th>Standard speed motor and booster pump</th>
<th>High speed motor</th>
<th>High speed motor and booster pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5,15</td>
<td>5</td>
<td>9,69</td>
<td>7,5</td>
</tr>
<tr>
<td>4</td>
<td>6,41</td>
<td>5</td>
<td>10,95</td>
<td>7,5</td>
</tr>
<tr>
<td>5</td>
<td>7,67</td>
<td>7,5</td>
<td>12,21</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>8,93</td>
<td>7,5</td>
<td>13,47</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>10,19</td>
<td>7,5</td>
<td>14,73</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>11,45</td>
<td>10</td>
<td>15,99</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>12,71</td>
<td>10</td>
<td>17,25</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>13,97</td>
<td>12</td>
<td>18,51</td>
<td>15</td>
</tr>
<tr>
<td>11</td>
<td>15,23</td>
<td>12</td>
<td>19,77</td>
<td>15</td>
</tr>
<tr>
<td>12</td>
<td>16,49</td>
<td>12</td>
<td>21,03</td>
<td>15</td>
</tr>
<tr>
<td>13</td>
<td>17,75</td>
<td>12</td>
<td>22,29</td>
<td>15</td>
</tr>
<tr>
<td>14</td>
<td>19,01</td>
<td>15</td>
<td>23,55</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>20,27</td>
<td>15</td>
<td>24,81</td>
<td>20</td>
</tr>
<tr>
<td>16</td>
<td>21,53</td>
<td>15</td>
<td>26,07</td>
<td>20</td>
</tr>
<tr>
<td>17</td>
<td>22,79</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>24,05</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>25,31</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.1.9.2 Determination of cable sizes to be used with transformers

The main purpose of this system is to save costs on the cables required for the power supply to the centre pivot.
Usually, with a voltage of 400 V, two transformers are used: one to increase the voltage from 400 V to 1 000 V and the other to decrease the voltage from 1 000 V to 400 V at the centre pivot. A Delta-Star 400/1 000 Volt step-up transformer and Delta-Star step-down transformer with a continuous earth conductor is suggested. (ECC, earth continuous conductor). All 1 000 Volt cables must be of the four core type with 1 000 / 600 Volt grading. The 1 000 Volt system must be a sealed system with a circuit breaker on the 400 Volt side.

The advantage here is that the higher voltage allows the use of a thinner cable for the same voltage drop, as the current in ampère reduces pro rata with the voltage ratio. The transformers also have distribution points, which make the system more flexible. The Eskom transformer must be tapped nominally plus 3% with the step-down transformer (at the pivot point) which must also be provided with a nominal tap plus 3%. The step-up transformer (at the Eskom transformer) must not be tapped. This means that if a circuit is drawn, the maximum current on the system will never be higher than nominal plus 6%.

Apart from the saving on the cable, there will also be a saving in labour as the installation cost of a 95 mm² cable is considerably higher than that of a 10 mm² cable because the thicker cable is more difficult to handle and transport.

Two transformer sizes, namely 15 kVA and 25 kVA are used. Therefore all operating demands smaller than 15 kVA will be served by the 15 kVA system while larger demands up to and including 25 kVA will be served by the 25 kVA system (see Tables 14.7 and 14.8).

Installation of the system is straightforward as junction boxes contain all fittings and are pre-wired. An electrical contractor will have to be employed to do the electrical installation and arrange for all tests and inspections, as specified, to be done. Overcurrent protection is compulsory, while the contractor has a choice to install the earth fault protection. He is responsible for the arrangement of all tests and inspections as specified.

- Cables
  All cables should be laid with at least 900 mm cover or beneath the main line. All cables in earth trenches must be laid on a 75 mm layer of river sand or sifted soil before backfilling of trenches commence. A 6 mm² copper earth cable from the control panel must be anchored to the earthing rod. The step-up and step-down transformer must be provided with two earth rods 5 metres apart. The one earth rod must earth the transformer box and the other the star point of the transformer.
### Table 14.7: Maximum cable length required if transformers are used [m] (standard speed motors without booster pump, maximum voltage drop 5%)

<table>
<thead>
<tr>
<th>Number of towers</th>
<th>15 kVA transformer</th>
<th>25 kVA transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current [A] @ 1000 Volt</td>
<td>Cable size [mm²]</td>
</tr>
<tr>
<td>1.0</td>
<td>2.06</td>
<td>2.04</td>
</tr>
<tr>
<td>2.0</td>
<td>3.07</td>
<td>3.05</td>
</tr>
<tr>
<td>3.0</td>
<td>4.08</td>
<td>4.07</td>
</tr>
<tr>
<td>4.0</td>
<td>5.09</td>
<td>5.08</td>
</tr>
<tr>
<td>5.0</td>
<td>6.09</td>
<td>6.08</td>
</tr>
<tr>
<td>6.0</td>
<td>7.10</td>
<td>7.09</td>
</tr>
<tr>
<td>7.0</td>
<td>8.11</td>
<td>8.10</td>
</tr>
<tr>
<td>9.0</td>
<td>10.12</td>
<td>10.11</td>
</tr>
</tbody>
</table>

*The current at 1000 Volt is obtained by multiplying the current at 400 Volt with 0.4 (Table 14.5)*
Table 14.8: Maximum cable length required if transformers are used [m] (high speed motors without booster pump, maximum voltage drop 5%)

<table>
<thead>
<tr>
<th>Number of towers</th>
<th>15 kVA transformer</th>
<th>25 kVA transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current [A] @ 1000 Volt</td>
<td>2,58</td>
<td>3,25</td>
</tr>
<tr>
<td>Cable size [mm²]</td>
<td>1,5</td>
<td>837</td>
</tr>
<tr>
<td></td>
<td>4,0</td>
<td>2 239</td>
</tr>
<tr>
<td></td>
<td>6,0</td>
<td>3 352</td>
</tr>
<tr>
<td></td>
<td>10,0</td>
<td>4 449</td>
</tr>
<tr>
<td></td>
<td>16,0</td>
<td>4 676</td>
</tr>
<tr>
<td></td>
<td>25,0</td>
<td>4 906</td>
</tr>
</tbody>
</table>

* The current at 1 000 Volt is obtained by multiplying the current at 400 Volt with 0,4 (Table 14.5)
Example 14.5:
Determine the cable size if 1 000 volt transformers will be used for a ten-tower centre pivot with high-speed motors. Distance from power point to centre pivot is 650 m.

Solution
Method 1:
From Table 14.8: 25 kVA transformer is required
4 × 4 mm² cable is to be used
16.94 ampère required

Method 2:
\[ \Delta V = 5\% \text{ of 1 000 Volt} \]
\[ = 50 \text{ Volt (phase to phase)} \]
\[ = \frac{50}{\sqrt{3}} = 28.86 \text{ volt (phase to neutral)} \]

According to Equation 14.13
\[ F = \frac{1000 \times \sqrt{3} \times 28.86}{6.78 \times 650} \]
\[ = 11.342 \text{ mV/ampère - metre} \]

According to Table 14.4, a 4x4 mm² cable must be used

2.2 Travelling irrigators

Travelling irrigators consist of a big gun sprinkler mounted on a trolley. The trolley moves slowly across the field while the sprinkler irrigates. Parallel strips are irrigated in this way.

Water is supplied by an underground main line, which is laid in the middle of the field. The sprinkler moves perpendicular to the main line in specifically spaced strips. Strip spacing depends on the wetted diameter of the big gun and varies between 60% and 80% of the diameter, depending on wind conditions. A hydrant is installed on the main line opposite each strip, for connection to the sprinkler. Actuation can take place by one of three methods:

- A drum on the trolley is hydraulically driven and rolls up a cable, which is anchored at the other end of the field. In this way the sprinkler is dragged across the field. The water source is connected to the sprinkler with a flexible hose, which is dragged behind the trolley. A disadvantage of this model is that it has a costly supply pipe, which can wear while an advantage is that a strip of up to 400 m can be irrigated per set.

- Another model consists of a drum around which the water supply pipe is rolled. The drum is mounted on a trolley. The big gun is connected to the supply pipe and mounted on a smaller trolley or sled. The large trolley is set up in the middle of the field directly opposite the main line. The big gun on the sled is then dragged to the edge of the field by tractor, unrolling the supply pipe from the drum. When the big gun begins to irrigate, the drum is hydraulically driven, rolling up the supply pipe and dragging the big gun in. When the sled reaches the trolley and drum, the trolley is rotated through 180° and the remaining half of the field is irrigated in the same way.

- The drum around which the water supply pipe is rolled and the big gun are mounted on the same trolley. The supply pipe of ordinary high-density polyethylene is connected to the hydrant on the main pipe at one end of the field. The trolley is then dragged to the opposite end of the field by tractor. When the water supply is activated, the trolley is hydraulically driven and moves all along the supply pipe to the hydrant. When the hydrant at the end of the strip is reached, the water supply is automatically cut and the machine is ready to be moved to the next strip. The advantage of this system is that strips do not necessarily have to follow a straight line. The supply pipe may be laid along the contour and the trolley, which has a steering mechanism, will follow it.
Travelling irrigators are especially suited to pastures and sugar cane, but are also applied to other types of agronomic crops. They still require more labour than centre pivots as they have to be moved once every 12 or 24 hours by tractor. They are generally used on uneven surfaces not suited for centre pivots but where travelling irrigators may be used practically. The moving direction must be such that the pressure difference between the upper and lower ends of a strip does not exceed 20% of the working pressure. The limiting factors with travelling irrigators are the condition of roads, prevailing winds and the high working pressure required.

The following design considerations apply to travelling irrigators:

- **Crop type**
  Travelling irrigators are usually used on pastures and vineyards. The system is not suited to vegetables due to its high application rate.

- **Crop water requirement**
  The peak irrigation requirement is determined for a specific crop.

- **Site**
  Determine the site dimensions and slopes. Try to limit cross slopes over the strips to less than 5%. A pressure regulator is recommended for travelling irrigators on steep slopes to ensure a constant flow rate.

- **Irrigation time**
  Determine the soil's readily available water holding capacity as well as the water availability, working hours per day and working days per week available for irrigation.

- **Flow rate**
  The following equation may be used to determine flow rate:

  \[
  Q = \frac{7 \ n \ B \ L \ NIR}{1000 \ t_d \ \eta_s \ t_h} \tag{14.14}
  \]

  where
  - \( Q \) = flow rate \([m^3/h]\)
  - \( n \) = number of strips/week
  - \( B \) = strip width \([m]\)
  - \( L \) = strip length \([m]\)
  - \( NIR \) = net irrigation requirement \([mm/day]\)
  - \( t_d \) = number of days irrigated/week
  - \( t_h \) = working hours/day
  - \( \eta_s \) = system efficiency \((0.75-0.8)\) \([\text{fraction}]\)

  This flow rate must be increased by \(\pm 2.5\ m^3/h\) to allow for driving water when a hydraulically driven travelling irrigator is used.

- **Sprinkler choice**
  Type of sprinkler and pressure may be chosen from manufacturer's catalogues. Big gun sprinklers with a high jet angle (> 23°) are only recommended for low wind areas. The following minimum working pressures are recommended to limit droplet size:

  - 300 kPa for 12 mm nozzles
  - 400 kPa for 14 mm and 16 mm nozzles
  - 500 kPa for 18 mm and 20 mm nozzles
• **Strip width**
  Try to set out strips perpendicular to prevailing winds if possible. Manufacturer's manuals may be used in choosing strip widths. Because of the influence of wind on travelling irrigators, most manufacturers recommend strip widths for different wind velocities as follows:

*Table 14.10: Reduction factors for travelling irrigator strip widths to allow for windy conditions*

<table>
<thead>
<tr>
<th>Wind velocity [km/h]</th>
<th>Strip width [% of wetted diameter]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 8</td>
<td>70%</td>
</tr>
<tr>
<td>8 - 16</td>
<td>60%</td>
</tr>
<tr>
<td>&gt; 16</td>
<td>50%</td>
</tr>
</tbody>
</table>

• **Friction**
  Pressure calculations are straightforward and only the friction losses in the main pipe and the connecting pipe need to be determined. Pump pressure is determined by sprinkler pressure, height difference and friction losses.

• **Total gross application**
  Gross application may be determined as follows:

\[
GA = \frac{1000 Q}{v B} \quad (14.15)
\]

where
- \(GA\) = gross application [mm]
- \(Q\) = flow rate \([m^3/h]\)
- \(v\) = speed of travelling irrigator \([m/h]\)
- \(B\) = strip width \([m]\)

To determine the net application on the ground, the above value must be multiplied by the system efficiency.

• **Gross application rate**

\[
GAR = \frac{1000 Q}{A} \quad (14.16)
\]

where
- \(GAR\) = gross application rate \([mm/h]\)
- \(A\) = area wetted by big gun \([m^2]\)

For a big gun with a certain wetted angle:

\[
GAR = \frac{1000 Q \times 360}{\pi R^2 x} \quad (14.17)
\]

where
- \(x\) = the wetted angle of the big gun sprinkler (degrees)
Net application rate

\[
\text{NAR} = \text{GAR} \eta_a \tag{14.18}
\]

where \( \eta_a \) = application efficiency [fraction] (that is system efficiency with no transport losses)

**Example 14.6:**
Design a travelling irrigator for 28 ha lucerne on a sandy loam soil. The net irrigation requirement of lucerne in the specific area is 4 mm/day, the effective root depth is 800 mm and 50% of the available water may be withdrawn for irrigation. The soil's infiltration rate is 8 mm/h and the water holding capacity is 115 mm/m. The field is rectangular with dimensions 200 × 1400 m. The farmer is prepared to work 6 days per week and requires 1 hour per set or strip for moving. Wind velocity may be taken as 10 km/h and system efficiency is 70%.

**Solution:**
Determine the minimum total flow rate to the field (assume two sets or strips per day, therefore working hours per day = 22):

From equation 14.1:

\[
\text{Flow rate} = \frac{A \times 10 \times \text{NIR} \times 7 \times \eta_a}{\text{ts.e} \times \eta_s} = \frac{28 \times 10 \times 4 \times 7}{22 \times 6 \times 0.7} = 84.85 \text{ m}^3 / \text{h}
\]

Determine the minimum big gun sprinkler radius (make the net application-rate equal to the soil's infiltration rate):

From equations 14.17 and 14.18:

\[
\text{Nett application rate} = \frac{1000Q \times 360 \times \eta_s}{\pi R^2 x}
\]

\[
R_{\text{min}} = \sqrt{\frac{84.85 \times 1000 \times 360 \times 0.7}{\pi \times 8 \times 360}} = 48.61 \text{ m}
\]

NB: If the radius or flow rate is too high, use two or more sprinklers. The flow rate as well as the minimum big gun sprinkler radius will change accordingly.

Determine the required abilities of the travelling irrigator in terms of application and travel speed (Chapter 11: Planning).
The travelling irrigator must be able to apply a net application of smaller than or equal to the readily available water, therefore:

\[
\text{Nett application} = \frac{115 \times 800 \times 50}{1000 \times 100} = 46 \text{ mm}
\]

\[
\therefore \text{ gross application} = \frac{46 \times 100}{70} = 66 \text{ mm}
\]

\[
\text{Theoretical cycle length} = \frac{\text{Nett application}}{\text{ett irrigation requirement}}
\]

\[
= \frac{46}{4} = 11.5 \text{ days}
\]

This is the only requirement as regards application for this example. If annual crops are to be cultivated it is possible that other maximum applications will come into play.

It will be ideal if the travelling irrigator can cover the 200 m strip in exactly 23, 11, 7 or 5 hours. This represents respectively 1 (24 - 1), 2 (12 - 1), 3 (8 - 1) and 4 (6 - 1) strips per 24 hours. Therefore, determine the travel speed for each of these running times:

\[
\nu_{23} = \frac{200}{23} = 8.7 \text{ m/h}
\]

The travel speed of 11, 7 and 5 hours are determined in the same way and found to be 18.2 m/h, 28.6 m/h and 40 m/h respectively.

Following the above, a travelling irrigator may now be chosen from a manufacturer’s catalogue.

From the catalogue none of the travelling irrigators can deliver 84.85 m³/h at a radius of 48.61 m, therefore consider using two travelling irrigators:

\[
Q_2 = \frac{84.85}{2} = 42.42 \text{ m}^3/\text{h}
\]

and

\[
R_{\text{min}} = \sqrt{\frac{1000 \times 42.42 \times 360}{\pi \times 8 \times 360}} = 41.08 \text{ m}
\]
A "Boss" travelling irrigator with a XXX-30 big gun sprinkler with a 22.8 mm nozzle delivers 44 m³/h at 450 kPa, the wetted diameter being 89 m (therefore big gun sprinkler radius is 45 m). The big gun sprinkler can also do full circles. Therefore the travelling irrigator complies with the requirements in terms of delivery and radius. With a wetted diameter of 89 m and a wind speed of 10 km/h the strip width may be as follows:

From Table 14.10: Maximum strip width = 0.6 × wetted diameter, therefore:

\[ B_{\text{max}} = 89 \times 0.6 = 53.4 \text{ m} \]

Therefore, two travelling irrigators must irrigate a field 1400 wide, one travelling irrigator doing 700 m. With \( B_{\text{max}} = 53.4 \text{ m} \) each travelling irrigator must then cover 14 strips of 50 m which fits in well with the field layout.

The travelling irrigator’s speed may vary from 8.3 m/h to 33.3 m/h. It will therefore be able to cover the 200 m strips in 23, 11 and 7 hours to allow for a one-hour moving period per set.

The cable length is 102 m, therefore the 200 m strips can easily be covered if water is supplied from the middle of the field, that is 100 m both ways.

From equation 14.15:

\[ \text{Gross application at minimum speed (} v = 8.3 \text{ m/h)} = \frac{1000Q}{vB} = \frac{1000 \times 44}{8.3 \times 50} = 106 \text{ mm} \]

The gross application at a travel speed of respectively 8.7 m/h, 18.2 m/h, 28.6 m/h and 33.3 m/h is determined in the same way and comes to 101 mm, 48 mm, 31 mm and 26 mm.

From the above it appears that the travelling irrigator must cover two strips per 24 hours with a gross application of 48 mm so as not to exceed the amount of water available to the plant (66 mm as previously determined) and also have a practical travel speed. Therefore the net application is as follows:

\[ NA = \frac{48 \times 70}{100} = 34 \text{ mm} \]

Maximum practical cycle length = \[ \frac{34}{46} \times 11.5 = 8.5 \text{ days} \]

But each travelling irrigator must cover 14 strips (1 ha each) per cycle and can irrigate two strips per 24 hours.

Number of days required to irrigate area = 7 days

Only six days per week are available

Practical cycle length = 8 days

The flow rate and pressure required for driving must also be taken into account if required.

### 2.3 Rotating boom systems

The design of rotating booms merely entails reading off applications per hour from manufacturer's tables. A suitable travelling time or standing time can be determined from the crop requirements and the soil water holding capacity.
It is important to note that a triangular spacing is used with a static boom as a rectangular spacing causes weak distribution with a dry area between the four positions. It is advisable to plot the positions and wetted circles on the site plans.

With rotating boom systems a strip spacing of 85% of the wetted diameter produces the best distribution efficiency, namely 91%.

**Example 14.7:**

Design a rotating boom for lucerne on a sandy loam soil with a basic infiltration rate of 8 mm/h and a water holding capacity of 115 mm/h (example 14.6).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net irrigation requirement</td>
<td>4 mm/day</td>
</tr>
<tr>
<td>Field area</td>
<td>28 ha</td>
</tr>
<tr>
<td>Root depth</td>
<td>800 mm</td>
</tr>
<tr>
<td>Allowable depletion</td>
<td>50%</td>
</tr>
<tr>
<td>System efficiency</td>
<td>70%</td>
</tr>
<tr>
<td>Moving time required per cycle</td>
<td>1 hour</td>
</tr>
<tr>
<td>Field width</td>
<td>400 m</td>
</tr>
<tr>
<td>Working days per week</td>
<td>6</td>
</tr>
<tr>
<td>Soil’s infiltration rate</td>
<td>8 mm/h</td>
</tr>
</tbody>
</table>

**Solution:**

Choose an RR sprinkler with the following specifications:

- Wetted diameter: 57 m
- Discharge: 30 m³/h

From equation 14.18:

\[
NAR = \frac{GAR \eta_a}{\pi d^2} = \frac{Q \times 4 \times 1000 \times \eta_a}{\pi d^2} = \frac{30 \times 4 \times 1000 \times 0.7}{\pi \times 57^2} = 8.23 \text{ mm/h}
\]

The soil’s infiltration rate is exceeded.

Now choose the RS sprinkler.

- Wetted diameter: 78 m
- Discharge: 38 m³/h

From equation 14.18:

\[
NAR = \frac{Q \times 4 \times 1000 \times \eta_a}{\pi d^2} = \frac{38 \times 4 \times 1000 \times 0.7}{\pi \times 78^2} = 5.57 \text{ mm/h}
\]

Now the soil’s infiltration rate is not exceeded. From the performance tables, the RS sprinkler has a discharge of 38 m³/h at a hydrant pressure of 260 kPa.

The field width of 400 mm is compatible with the possible strip length of the rotating boom, therefore the number of strips can be determined.

\[
\text{Field length} = \frac{28 \times 10^4}{400} = 700 \text{ m}
\]
Recommended strip spacing for the RS sprinkler is 75 m.

\[
\text{Number of strips} = \frac{700}{75} = 9.33
\]

Using 10 strips, the strip width becomes 70 m.

Information for determining the rotating boom’s application is the same as determined in example 14.6: \(GA = 66\) mm.

From equation 14.15:

\[
\text{Travel speed (v)} = \frac{1000 Q}{GA B} = \frac{38 \times 1000}{66 \times 70} = 8.23 \text{ m/h}
\]

Working time available per day = 23 hours

Therefore the rotating boom can irrigate 189 m per day.

If irrigation continues unabated for two days before moving, 386 m can be irrigated in 47 hours.

For practical reasons it must be attempted to irrigate a strip length of 400 m in 47 hours.

\[
\text{Therefore travel speed} = \frac{400}{47} = 8.5 \text{ m/h}
\]

Total strip length to be irrigated:

\[
\text{Field area} = \frac{280000}{70} = 4000 \text{ m}
\]

Time taken to irrigate 4000 m at 8.5 m/h = \(\frac{4000}{8.5} = 470.6\) h

Number of days required per irrigation = \(\frac{470 \times 2}{47} = 20\) days

However, the theoretical cycle length is 11.5 days (see example 14.6).

Choose a practical cycle length of 10 days and therefore use two travelling booms.

Because of the increase in travel speed, the application will decrease:
\[
\text{Therefore } GA = \frac{1000Q}{vB} = \frac{1000 \times 38}{8.5 \times 70} = 64 \text{ mm}
\]

The actual application to be given (practical cycle length is shorter):
\[
= 66 \times \frac{10}{11} = 60 \text{ mm}
\]

Therefore sufficient water is applied per cycle length.

Larger applications may be achieved by using a different sprinkler package with a wider strip width. The opposite applies to smaller applications.

### 2.4 Linear systems

Linear systems are very similar to centre pivots as regards construction except that they do not rotate about a central point.

Driving is usually electrical or hydraulic with a diesel motor mounted on the machine or also electrical or hydraulic where an external pump with draglines is used.

Water is supplied by:

- a channel in the middle or at the side of the field, parallel to the movement direction from which the linear system's motor pumps the water;
- hydrants which are connected to the linear system with a flexible drag-line and make use of pressure from an external pumping station; and
- an automatic coupling system where the linear system is coupled to the hydrants and use is also made of an external pump.

The system is guided by censors, which follow a cable stretched across the length of the field. Switches or valves on each tower, which keep each span length in line, further accomplish linear system routing.
3 References


2. Reinders, F. *Gemeganiseerde besproeiing*. Directorate Irrigation Engineering, Silverton. RSA.

APPENDIX A

INFILTROMETER

- **Description of apparatus**
  The infiltrometer consists of a sprinkler with a V-nozzle, which rotates within a shield.

  Water is siphoned from 400 ℓ containers, with a flexible pipe into the circulation container, which also forms the base. Water is drawn from the circulation container and delivered to the H½U 80 - 100 V-nozzle sprinkler through a stand pipe, by a self-priming pump with a capacity of 3,6 m³/h and a pressure of 65 kPa. The sprinkler rotates within a shield with a flow slot, which wets a representative area. Water deflected from the inside of the shield is fed back to the circulation container.

  The application rate, which varies with distance from the infiltrometer, is measured by means of a stopwatch and four rain-gauge tops and recorded directly on the given nomogram.

  The infiltrometer is a compact, portable unit with a total mass of less than 20 kg.

- **Choice of test site**
  The test should be done on the dominating soil types of the farming unit with the soil surface and moisture content the same as before an irrigation. The worked soil should have been irrigated twice or more or had rain, the reason being that crust formation and its influence on crust forming soils and the ground-water status with non-crust-forming soils should be taken into account with these tests.

  The results of the soil with the weakest infiltration ability are then used as the criteria.

- **Preparation of test site**
  As crust formation dictates infiltration ability with crust-forming soils, it should already have taken place or been artificially created before the test.

  An artificial crust can be created by wetting a previously worked area of at least 3 m × 3 m with 15 litres of water per m². This can be done with a hosepipe. Wait 7 days before performing the test as a hard crust will form with drying. The test may also be carried out before 7 days have passed if the upper 10-20 mm has dried out completely. To get the initial feeling of how a crust should be formed, it may be necessary to create an artificial crust on a site, which has already had rain. Two infiltration tests are then performed and the results compared; one on the undisturbed soil (rain only) and one on the artificial crust.

- **Setting up the infiltrometer**
  The infiltrometer's application-rate decreases with an increase in distance from the apparatus as shown in Figure 14.7. This phenomenon creates the opportunity to evaluate the soil's accumulative infiltration at a number of points.
Erect the apparatus directly next to the chosen test site with the slot facing in the wind direction. Place base-sealed rain gauge tops at 0.5 m spacing as shown in Figure 14.8. Use one or two sprinklers and fill the sealed container with water. The test may now begin.

Use one or two V-nozzles (two nozzles produce a higher application rate) although one V-nozzle should be sufficient for most soils.

The test may begin when the circulation container has siphoned full of water.

- **Test procedure**
  Record the time and activate the pump. The working pressure must be 65 kPa. After a certain time a wetting front forms, which moves away from the apparatus. This coincides with the forming of surface water. As soon as the front passes the water shadow (see Figure 14.9) of the first measuring points, the time is recorded and the application measured.
The other measuring points will be treated in the same way. At least three measuring points are required for a reliable test result, the last measuring point test lasting at least thirty minutes. The results are then directly recorded on the given nomogram and the accumulative infiltration curve fitted.

The nomogram with fitted curve is now ready for the design of a moving irrigation system.

The design form with recorded test results can be filed to create a handy database for different soils.
## TEST AND DESIGN FORM

**DATE:** ..........................................................  **FARM:** ..........................................................

**OWNER:** ......................................................  **DISTRICT:** .......................................................

### Location

<table>
<thead>
<tr>
<th>Soil type:</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil series:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Texture class:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Surface:**

- (Treated or not)
- (Tilling practice)

- Max. slope [%]

### Infiltration test

<table>
<thead>
<tr>
<th>Measuring point</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>[mm]</td>
<td>[min]</td>
<td>[mm]</td>
<td>[min]</td>
<td>[mm]</td>
</tr>
</tbody>
</table>

### LOCATION PLAN

- Suggested centre pivot
- Suggested linear system

- Indicate:
  - North arrow
  - Where test is performed

### Design information

- Gross application   \( GA = \) .............................................................. [mm]
- Surface storage \( S = \) .............................................................. [mm]
- Infiltration equation \( I = \) .............................................................. [mm/h]
- Maximum gross application rate \( GAR = \) .............................................................. [mm/h]

### Table

<table>
<thead>
<tr>
<th>Distance from centre [m]</th>
<th>Strip width (B) [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Company:** ..............................................................

**Designer:** ...............................................................

**Date:** ...............................................................
Example 14.8:
A moving irrigation system must be designed for a field of 800 × 800 m. The net irrigation requirement is 8 mm/day and the steepest slope is 2%.

An infiltration test was performed, giving the following results:

<table>
<thead>
<tr>
<th>mm</th>
<th>minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>23</td>
<td>45</td>
</tr>
</tbody>
</table>

Assume the following:

- Gross application \( GA = 25 \text{ mm} \)
- System efficiency \( \eta_s = 85\% \)
- Working hours per day \( t_h = 24 \text{ hours} \)
- Working days per week \( t_d = 6 \text{ days} \)

A 50 ha centre pivot or a linear system of 400 m with a travel distance of 1 600 m will fit in on a field of 800 × 800 m.

Solution:
Use the accompanying nomogram for the solution.

Step 1:
Plot the infiltrometer test values on the logarithmic graph and fit a line between them (this is the accumulative infiltration line). Use graph A of the nomograph for this.

Step 2:
7.5 mm surface storage is permitted with 2% land slope (Table 14.2). Now find the intersection with the cumulative depth of 17.5 mm (this is: gross application of 25 mm minus surface storage 7.5 mm). Therefore the system’s gross application rate can be a maximum of ± 56 mm/h (between 50 and 60 mm/h gross application-rate lines).

Note: The contact time of 26 minutes is determined by the intersection of the gross application-rate (56 mm/h) and the required gross application (25 mm).

Step 3:
Determine the gross application requirement on graph D by moving up vertically from the net irrigation requirement (8 mm) to the required system efficiency (85%), right horizontally to the number of working hours per week, namely 144 (6 × 24) and then vertically downwards. The gross irrigation requirement of 11 mm is then read off. This value will be used on graph B.

Step 4:
Back to graph A. Move along the 56 mm/h gross application-rate line to the gross application requirement curves on graph B and intersect with 11 mm.

Step 5:
Move right horizontally to the wetted strip widths on graph C. Here different options for minimum strip widths to be adhered to for every length, area or travel distance are given.

In this example the centre pivot area and therefore length is fixed. The intersection of area = 50 ha, that is a length \( l = 400 \text{ m} \), and the horizontal line from graph B is \( B = 20 \text{ m} \) minimum wetted strip width. This means that this restriction applies at the farthest point (400 m) from the centre pivot. Closer to the centre, say at 300 m, a 15 m strip width will suffice. The wetted strip width at any point may be achieved with a single sprinkler or a sprinkler-boom combination.

A linear system with a travel distance of 1 600 m will require a wetted strip width of ± 13 m. This may be a sprayer-boom combination.
Figure 14.10: Design nomogram for moving systems