5.5 Centre pivot and lateral move systems

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Key points

- Ensure the system capacity of centre pivots and lateral moves (CPLMs) is large enough, when managed correctly, to keep up with peak crop water requirements.
- Using larger diameter pipe spans costs more, but lifetime running costs are dramatically reduced.
- Sprinkler packages represent less than 7% of the capital investment but are responsible for 70% of the irrigation performance.
- Modern low pressure sprinklers have application efficiencies up to 95% and LEPA systems have application efficiencies up to 98%.
- Wheel ruts and bogging will reduce as tracks compact and can be overcome by modifying flowrate, sprinkler type and emitter location around towers to avoid placing water in wheel tracks.

- Ensure that all water drains from span pipes, to avoid corrosion. Test irrigation water quality before you buy a system, to ensure compatibility of irrigation waters and pipe coatings.
- Continue irrigation long enough after fertigation has finished to ensure machine is fully flushed.

This chapter has been updated with information from the Centre Pivot and Lateral Move training course developed by the CRC for Irrigation Futures. This course contains the most up to date information on centre pivot and lateral move irrigation in Australia and is strongly recommended for those who currently manage or are interested in purchasing these systems. This training is currently provided by a number of providers including NSW DPI and Growcom.

Additional background material and insights from current CPLM users is contained in the publications CPLM machines in the Australian cotton industry (2001) and Review of CPLM systems in the QMDB (2011) which are also strongly recommended.
History of centre pivot and lateral move machines

Centre pivot and lateral move irrigation machines (CPLMs) represent the largest (in both physical size and flow rate) of the mobile machines used by growers to apply water to crops and fields. The first CPLMs were developed in the late 1940s with the patenting of a ‘self-propelled sprinkling irrigation apparatus’ by Frank Zybach in Nebraska. A.E. Trowbridge manufactured these early machines. Prior to this time, sprinkler irrigation was commonly performed using steel pipe and impact sprinklers, as aluminium pipe was only just becoming available. These early centre pivot machines consisted of towers that supported the pipes via suspension cable and were powered by the irrigation water pressure using hydrostatic drives at each wheel set. The right to manufacture these machines was acquired in the 1950s by Robert Daugherty who began manufacturing under the ‘Valley’ brand name. The first Australian innovation in this arena saw the Layne and Bowler Company of the USA introduce the Australian Raincat ideas of electric motor drives, today’s standard bowstring truss suspension and track drives which were later replaced with rubber tyres. During the 1960s, machines also started to be manufactured with water piston or water spinner drives rather than oil hydraulic drives. The standard machine manufactured prior to 1970 was a high-pressure unit (~80 psi at the centre) fitted with large impact sprinklers located along the top of pipe. However, the energy crisis in the early 1970s resulted in the introduction of low-pressure static plate sprinklers located on droppers below the pipe. These modifications meant that the machines could be operated at much lower pressures (<40 psi) with lower operating costs.

By the mid-1970s, centre pivot and lateral move machines were rapidly starting to dominate the new and expanding irrigation developments in the USA and the Middle East. Of the 25.6 million hectares currently irrigated in the USA, approximately 32% (or 8.1 million hectares) is irrigated with this equipment. Centre pivots were first introduced into Australia in the 1960s, primarily in South Australia and Victoria. Centre pivot and lateral move machines currently irrigate 8% to 10% of the total irrigated area in Australia. Centre pivot irrigation of cotton has been undertaken in the USA since the late 1960s and in Australia since the early 1970s.

The last thirty years have seen the four main CPLM manufacturing companies based in Nebraska (Valley, Lindsay Zimmatic, T&L, and Reinke) dominate the world market for these machines. There are approximately 500 machines sold in Australia each year and around thirteen manufacturers or distributors. However, the majority of the machines available in Australia are manufactured in either the USA or Europe, with only a handful being manufactured by Australian companies.

In most cases, the irrigators are imported as whole machines. Most manufacturers produce lateral move machines, but USA based companies in particular are often not interested in supplying them due to the comparatively small market size and the additional level of complexity associated with controlling and guiding these machines.

CPLM Adoption Drivers

Since the late 1990’s, there has been renewed interest in CPLM systems in the cotton industry, and the amount of local research over this time has also increased in response. Notably, users of CPLM systems have been interviewed in both 2001 (across the whole cotton industry) and 2011 (across the Queensland Murray-Darling Basin only), providing a range of insights into why growers are finding these systems attractive and how they are being used. The full results of these studies are strongly recommended for irrigators considering these systems.

Most growers cite labour and water savings as their main motivation for installing CPLM systems (Table 5.5.1). In the 2011 study, the median labour requirements for centre pivot and lateral move systems were found to be 20% and 40% of that required for an equivalent area of furrow irrigation, respectively.
Table 5.5.1 - Comparison of issues driving adoption in 2001 and 2011

<table>
<thead>
<tr>
<th>Issue</th>
<th>2001 Response</th>
<th>2011 Response</th>
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<tr>
<td>Labour Saving</td>
<td>85%</td>
<td>90%</td>
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<tr>
<td>Water Saving</td>
<td>93%</td>
<td>87%</td>
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<tr>
<td>Reduced Waterlogging</td>
<td>73%</td>
<td>60%</td>
</tr>
<tr>
<td>Improved Water Application Uniformity</td>
<td>65%</td>
<td>40%</td>
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<tr>
<td>Fertigation (including chemigation)</td>
<td>46%</td>
<td>30%</td>
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<tr>
<td>Increased Crop Yield</td>
<td>46%</td>
<td>23%</td>
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<tr>
<td>Improved Crop Quality</td>
<td>12%</td>
<td>20%</td>
</tr>
<tr>
<td>Automation</td>
<td>58%</td>
<td>20%</td>
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<tr>
<td>Chemigation</td>
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<td>7%</td>
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In terms of water use, growers in the 2001 study tended to see greater improvements in Irrigation Water Use Index (IWUI, bales/ML), which may be because furrow irrigation performance across the industry has increased over the last decade with improved management practices. Still, over 40% of growers in the 2011 study believed they could achieve between 0.5 and 1.5 bales of extra production per ML of irrigation water with CPLM systems compared with furrow irrigation (Figure 5.5.1).

Figure 5.5.1 - Increase in irrigation water use index (IWUI) for cotton irrigated by CPLM compared to furrow irrigation in (a) 2001 and (b) 2011.

Other adoption drivers include the ability to irrigate a range of crops, to irrigate soil that was marginal for surface irrigation, to capture increased rainfall and to irrigate greater slopes. Individual growers have also found advantages in the ability to increase cropping intensity and to better implement minimum till practices than under furrow irrigation.
5.5 Centre pivot and lateral move irrigation systems

Equipment overview

Centre pivot systems are usually no longer than 500 metres, with the most common size being around 400 metres long. Lateral move machines are not commonly used overseas, and, when used in other crops, are rarely greater than 500 m long. The popularity of large machines in the cotton industry has resulted in lateral move machines of up to 1200 m in length being installed locally.

The main components of these CPLMs are the self-supporting frame spans. These structures use the water delivery pipes (located along the backbone of the span) as compression members that are held together by tie-rods acting as tension members. The pipe spans are supported at each end by a tower that incorporates gearboxes, drive wheels and either an electric or a hydraulic drive motor. Emitters (either sprinkler heads or low energy precision application fittings) are attached either directly to sockets on the main pipe or suspended closer to the crop on either rigid or flexible droppers.

Flexible mechanical and hydraulic couplings that allow the separate spans to act as individual elements connect individual spans. This ensures flexing, rotating and twisting of the joint and spans so that the machine can traverse land contours and obstacles. Machine speed governs the volume (depth) of water applied in each pass, while system alignment is maintained via micro switches, alignment levers and control equipment.

Centre pivots consist of a number of spans attached to a fixed centre tower containing a water supply point and power source around which the other spans and towers rotate (Figure 5.5.2). Lateral move machines are constructed in a manner similar to centre pivot machines except that they do not have a central rigid supply point: instead, they have the water supply point located either in the middle or at one end of the machine on a cart-tower assembly containing a mobile power plant. Lateral move machines that are supplied from open channels are provided with a large lift pump, while hose-supplied systems are fitted with an attachment point for connection to the watermain hydrant via a flexible water delivery hose.

Spans and pipe sizes

Spans commonly range in length from 34.2 m (113 ft) to 62.4 m (206 ft) with variations in exact size between different manufacturers. Span lengths are commonly limited due to the weight associated with the pipe itself and the volume of water transported. Internal diameters of the span pipes range from 135 to 247.8 mm with the most common pipe sizes being 162, 197 and 213 mm. Typical pipe wall thickness is about 2.77 mm (0.11”) for these systems.

Sprinkler Package

The sprinklers, nozzles and pressure regulators along the length of CPLMs are all part of the sprinkler package, and together they represent about 7% of the capital cost but are responsible for 70% of the irrigation performance. In the 1960s, CPLM irrigation systems had standard high-pressure (greater than 50 psi or 340 kPa) impact sprinklers mounted on top of the spans.

Modern low pressure sprinklers were developed to operate at less than 30 psi (200 kPa) to minimise energy requirements and have a larger and more consistent droplet size that results in very minimal evaporation. Low energy precision application (LEPA) systems were also developed to apply water directly onto the soil surface or below the crop canopy to eliminate evaporation from the plant canopy and reduce the wetted soil surface and soil surface evaporation.

Most modern emitter components (either sprinkler or LEPA attachment) are plastic with interchangeable components so that, for example, nozzle size or plate type can be easily changed. The components are often colour coded for ease of reference.

Figure 5.5.2. Centre pivot irrigation machine showing centre tower, spans, and wheel towers
For centre pivots, as the radial distance from the centre of the pivot increases, each emitter must provide water for an increasingly larger concentric ring of field area (Table 5.5.2). This is achieved by increasing nozzle size whilst maintaining emitter spacing, maintaining nozzle size whilst decreasing emitter spacing or a combination of both.

The result is a set of sprinklers and nozzles that are precisely specified for each outlet. If the wrong emitter is put in the wrong location, the performance of the package can be completely upset. Diligence is needed here by installers and by maintenance crews to ensure the correct emitter is put in the correct location to start with, and that they are kept there whenever maintenance is done.

This is not an issue on lateral move systems where sprinkler spacing and nozzle size is generally not altered along the length of the machine when pressure regulated. However, nozzle sizes across any machine should not be changed without considering the impact on the whole system and the possible changes to pump operation that may be required.

Table 5.5.2 – The proportion of total water applied from successive centre pivot spans (G Harris, DAFF Queensland)

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<thead>
<tr>
<th>Number of Spans</th>
<th>5 Span</th>
<th>6 Span</th>
<th>7 Span</th>
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<th>11 Span</th>
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LEPA

Low energy precision application (LEPA) irrigation was developed in the 1980’s on the water-short Texas High plains where deficit irrigation is prevalent and system capacities are low. The original concept combined double-ended socks and furrow dykes (small mounds or dykes in the furrows to trap small pools of water, preventing runoff and allowing infiltration to occur) although bubbler systems which drop water directly onto the soil surface are also available (Figure 5.5.3).

Figure 5.5.3. Emitter options for low energy precision application

(a) Drag sock

(b) Quadspray in bubbler mode
Both types of head are commonly suspended from the main pipe by flexible hose at either one or two crop row intervals. Drag socks come in both double and single ended sock options. Double ended socks are used in conjunction with furrow dykes, or tied ridge structures, to reduce the risk of washing these structures away (Figure 5.5.4). Bubbler units typically consist of either a “bubbler clip” attachment to a static plate sprinkler or a special “Quadspray” unit which has four operating modes that allow water to be either bubbled out in a low-pressure circular sheet, sprayed horizontally (germination mode), sprayed vertically upward (chemigation mode) or dribbled out directly from the bottom (Figure 5.5.5). Changeover from one operational mode to another only involves a click and twist rotation.

**Figure 5.5.4. Operation of a double-ended LEPA drag sock in conjunction with furrow dykes**

Drag socks are replaced with static plate sprinklers for crop germination and are positioned well above the soil surface to ensure good sprinkler overlap. It is important when using static plate sprinklers for germination that the sprinklers are placed at the height typically needed for the sprinkler throw. Often droppers have a connection at normal sprinkler height which is used for germination and an additional hose length is added when changing to LEPA mode so that the drag hose or bubbler outlet is close to the ground. Where any LEPA system is employed, there is both a time and labour requirement after crop establishment to allow changeover from the static plate sprinklers to the LEPA heads.

LEPA systems have very high average application rate (AAR – see below) because all of the nozzle flowrate is applied to a very small area of the soil surface. Even under the deficit irrigation and low system capacity conditions in which LEPA originally developed, furrow dyking was used to prevent surface water movement and runoff and allow time for water to infiltrate.

Despite LEPA being applied in Australia to high system capacity installations practicing full irrigation, furrow dyking has been uncommon and many growers prefer not to use LEPA socks because they tend to wear out due to the constant contact with the ground.

It is therefore not surprising that growers who install LEPA systems in Australia may have problems with water running along furrows and potentially resulting in runoff, wheel rutting or bogging. In cotton growing areas, natural soil cracks are commonly used instead of furrow dykes to retain water where it is placed, although this is not successful in all cases. Other practices such as stubble retention and rough, cloddy cultivation in furrow bottoms may be helpful for increasing the water retention capacity.
Sprinklers

Sprinklers are widely used on CPLM machines and are typically offered as standard fittings. While overhead and top-of-pipe sprinklers were common on older machines, newer machines are typically configured with over-crop sprinklers that hang down from the pipe (Figure 5.5.6).

Figure 5.5.6. Over-crop sprinkler irrigation

These over-crop sprinkler heads are available as either static or moving plate sprinkler heads. Static plates are a simple design with no moving parts. They consist of a nozzle which discharges water at a fixed plate which typically has a number of grooves in it (Figure 5.5.7). There are a range of configurations available to give different numbers of streamlets and different streamlet angles. Greater number of streamlets means finer drops are produced. Their simple design means they do not wear out quickly. The operating pressure is commonly 6 to 15 psi.

Figure 5.5.7 – A modern static plate sprinkler in operation (left) and an example of a ‘triple deck’ sprinkler with large nozzle and three levels of static plates.

Static plate sprinklers typically have the shortest throw distance of modern sprinkler types and their fixed streamlet pattern can result in high instantaneous application rates (IAR – see below). This may cause problems with erosion and soil crusting.

Such issues may be addressed by the use of moving plate sprinklers, by dividing the flow amongst a greater number of static plate sprinklers (with the use of spreader bars or boombacks) or by reducing nozzle sizes during early season irrigation whilst the soil is bare. Special static plate sprinklers with multiple plates also exist (e.g. Figure 5.5.7) which increase the number of streamlets, although these can be more prone to becoming clogged with trash.

Where static plate sprinklers are used for germination (e.g. LEPA bubbler systems) an alternate, smaller, nozzle is often used for the duration of the germination period. A dual nozzle clip is available to keep the alternate nozzle attached to the sprinkler body when not in use. As previously mentioned, it is especially important to employ the correct nozzles in the correct positions for centre pivot machines, and to adjust the pump appropriately for the reduced nozzle system flow rate.

Moving plate sprinkler heads are newer technology. They operate at slightly higher pressures than static plate sprinklers (10 to 30 psi) and can generally be divided into three groups:

- Lower pressure, fast rotation (e.g. Spinners)
- Higher pressure, slow rotation (e.g. Rotators)
- Lower pressure, fast oscillation, multi-path (e.g. I-Wobb)

On moving plate sprinklers, the plate
moves due to the force of the water jet hitting the plate grooves. Moving plates produce a greater throw (wetted footprint), a more controlled droplet spectrum and a decreased IAR compared to the same number of static plate sprinklers. The larger wetted footprint also reduces average application rate which can be helpful in circumstances where runoff could be an issue. Slower rotating units produce moving streamlets whilst the spinning and wobbling variants produce a continuous shower of droplets (Figure 5.5.8).

Figure 5.5.8 - Rotating and wobbling plate sprinklers in action. Note the break-up of streamlets into droplets in both moving plate sprinkler types.

However, the lower the sprinkler head pressure, the larger the droplet size. Modern low-pressure sprinklers impart roughly 60% of the energy of old top-of-pipe high-pressure impact sprinklers (Kincaid, 1996). Hence, low pressures and large numbers of streamlets typically provide the best result in terms of reducing the instantaneous application rate, reducing the impact energy imparted to the soil and increasing the throw distance. These benefits typically minimise surface crusting and reduce run-off.

It is also relevant to briefly mention end guns, which are often fitted to centre pivots. They are viewed as a cheap way to increase the area covered or to attempt to irrigate the corners of centre pivot fields. They have a large gun with a large nozzle requiring high pressure to propel the water stream and make it break up for even application. Fitting these to a CPLM is putting together two different types of irrigation system, creating two different types of irrigation pattern, application rate and uniformity.

End guns normally apply less water than the rest of the system, and do so with poorer uniformity. The extra energy required to operate them negates one of the benefits of low pressure sprinklers. The usual result of using them is poorer crop performance compared to the rest of the system, higher operating costs and soil surface problems. It is inadvisable to fit these as it is usually false economy.

It is generally accepted that the replacement of older sprinkler technologies (both top-of-pipe and static head over-crop sprinklers) on existing CPLMs is a relatively simple and cost effective way of improving system performance. In general, the larger the number of streamlets produced by the emitter the smaller the droplet size and the lower the drop impact energy applied to the soil surface.
Trends in emitter use

Despite being developed in the 1980’s, LEPA systems were not often used in Australia until they gained some interest in the cotton industry with a number of newly installed machines in the late 1990’s and early 2000’s. A 2001 study showed that by this time, 48% of growers using CPLM systems in the cotton industry used LEPA emitters (Figure 5.5.9). However a recent study (2011) using the same methodology found that only 20% of growers were using LEPA, although this subsequent study was limited to the Queensland Murray-Darling Basin and also included some grain irrigators.

Furthermore, the proportion of growers utilising moving plate sprinklers between these two studies increased from 4% to 67% and the use of static plate sprinklers decreased from 48% to 10%. Some of the growers who were featured in both studies had previously installed LEPA due to a range of previous concerns with sprinkler irrigation (such as potential effects on pollination or lint quality) which did not eventuate in practice and they have subsequently switched to sprinkler irrigation.

Sprinkler irrigation evaporation is another concern that may drive growers towards the use of LEPA systems, but modern sprinkler packages have been demonstrated to have very low evaporative losses, with maximums in the order of 0.5% (see below).

Infiltration under sprinklers and LEPA

When choosing an emitter type, growers are often interested in understanding how water might infiltrate into the soil in their field. Whilst the specific circumstances of each field and irrigation application will differ, researchers at the National Centre for Engineering in Agriculture produced a number of two dimensional images of soil moisture changes under different soil type, deficit and emitter types to demonstrate broad trends.

Figure 5.5.9 includes a number of images demonstrating the change in soil moisture due to CPLM irrigation events in a range of conditions. Each image shows a one metre transect of the plant row, from furrow to furrow, to a depth of one metre. The result is a one metre by one metre grid of soil moisture. An arrow indicates the furrow in which LEPA irrigation is applied (where applicable)

Each image shows the change in soil moisture from ten minutes before an irrigation event to ten minutes after the irrigation event. In each case, the intensity of blue colour indicates how much water has been added to the soil at that point, whilst white means no change in soil moisture and red means a decrease in soil moisture. As can be seen, some images show the plant continuing to use moisture at depth during the irrigation event whilst moisture is being added higher in the profile.

A range of scenarios were investigated, including cracking black and sealing red soils, both sprinkler and LEPA emitter types as well as a number of soil moisture deficits and irrigation application depths. Whilst the full range of results can not be included here, the patterns produced showed that water was rapidly redistributed through the profile in soils with cracks, even quickly moving through the plant line into non-watered furrows under LEPA irrigation. When the initial soil moisture deficit was low, irrigation water tended to stay in the upper soil layers as deeper layers were already moist and cracks were not evident. Infiltration under sprinkler irrigation on hardsetting or sealing soils was generally quite even and tended to infiltrate to the limit of existing moist soil.
Figure 5.5.10 – Change in soil moisture under a range of CPLM irrigation conditions from ten minutes before irrigation to ten minutes after irrigation. Blue colour indicates increase in soil moisture whilst red indicates a decrease in soil moisture. Arrows indicate furrow in which LEPA irrigation is applied.

- **Black Cracking Clay**
  - LEPA Bubbler
  - 80 mm soil deficit
  - 50 mm application
  - Irrigation water rapidly infiltrates the soil to depth, indicating flow through cracks. Soil in the non-watered furrow is also rapidly filled demonstrating the rapid redistribution of water throughout the profile.

- **Black Cracking Clay**
  - LEPA Bubbler
  - 30 mm soil deficit
  - 30 mm application
  - This irrigation was applied 24 hours after that in the previous image. Irrigation stays near the soil surface as the deficit was now much lower and the cracks were closed. Water still moves through the plant line to the non-watered furrow. Some extraction of water at depth.

- **Black Cracking Clay**
  - Sprinkler
  - 90 mm soil deficit
  - 26 mm application
  - Water infiltrates to a depth of 500 to 600 mm across the profile.

- **Red Hardsetting Soil**
  - Sprinkler
  - 50 mm soil deficit
  - 24 mm application
  - Water infiltrates to a depth of around 600 mm, preferentially filling some drier areas that existed at around 400 mm
Pressure Regulators

Pressure regulators are fitted on the drop tubes above the emitters. They are used to limit the maximum pressure at individual nozzles to aid in the control of:

- flow rate variation across the system length;
- desired droplet size;
- distribution uniformity; and
- sprinkler streamlet throw.

Variation in individual sprinkler pressure arises from variations in height due to terrain or emitter placement and pressure loss down the pipeline on the spans. It has become common practice to fit regulators to all machines. Whilst there are situations where pressure regulators may not be required on some systems, their use is common when very low pressure sprinkler packages (6 and 10 psi) are used.

The system pressure above the pressure regulator at the worst-case situation (i.e. the emitter at the outer end(s) of the machine while at the highest spot in the field) should be (3 – 5 psi) higher than that specified on the pressure regulator to ensure the regulator operates correctly. Check that regulators are the correct pressure rating for the sprinkler package – it is common for a system to be designed with emitters operating at a specified pressure and to be supplied with incorrectly rated regulators.

Boombacks

Boombacks are used to suspend the emitters at a distance of 3 to 6 m behind the machine towers (Figure 5.5.11). These optional fittings are used to improve the uniformity of sprinkler application to the crop near the towers and to reduce the potential for irrigation water intercepted by the tower (Figure 5.5.12) causing either rutting or bogging. Where the machine is required to move in both directions, boombacks can be fitted to both sides of the tower with the appropriate set of emitters selected using either manual or automated valves. Alternatively, a single boomback mounted on a hinged fitting can be used and swung either side of the towers, depending on the direction of travel.

Figure 5.5.11. Fixed and swivel mounted boombacks for CPLMs 1 m

![Fixed and swivel mounted boombacks for CPLMs 1 m](image)

Figure 5.5.12. Field test results showing three times the normal amount of water being applied around the tower through interception of sprinkler water by tower structure

![Field test results showing three times the normal amount of water being applied around the tower through interception of sprinkler water by tower structure](image)

Source: Foley 2000
Tyres and wheel sizes

CPLMs represent a considerable investment in tyres and wheels, so growers should also ensure that they have the necessary equipment to re-inflate, replace or otherwise repair tyres on the machine. This typically involves having spare tyres, along with lightweight jacks and blocks.

Larger tyre sizes are sold as options to reduce wheel rut formation. Common tyre sizes for centre pivot and lateral move machines include 14.9' × 24', 16.9' × 24', 16.9' × 28' and 11.2' × 38'. However, these sizes result in ground pressures for a wet 48 m span (weight ~ 3750 kg) with a 100 mm deep wheel rut of 12.9, 11.4, 10.8 and 14.6 psi respectively. Hence, while there are some differences in ground pressure associated with changes in tyre size, larger tyres do not generally reduce rutting as much as boombacks, which reduce the wetting of the wheeltrack area. Larger wheel and tyre sizes also increase loading upon gearboxes and drive trains. Tyre wheel combinations can also be purchased in sizes up to 18.4' × 28', 16.9' × 34' and 16.9' × 38'. However, manufacturers do not normally like to supply these larger sizes because of the higher drive train loads involved.

High speed ratios are also sometimes sold as solutions to wheel rutting problems. However, high speed drive-train combinations may produce start-up torques that are greater than the design specification for the machine, leading to increased occurrences of motor burnout. Gearbox failures are also often the result of overloading the machine drive-train. Larger width tyres may result in tyre centrelines that overhang from the gearbox attachment points, thus increasing the risk of failure. Where larger and wider tyres are used, the power cable size and hydraulic lines should be increased in capacity to cope with the greater power requirements.

Guidance

Guidance is a critical component of lateral move systems which, unlike centre pivots, are not tethered at one end and are therefore able to move freely of their own accord. Historically, poor guidance has been one of the factors leading to increased labour requirements for lateral moves over centre pivot systems, although guidance systems have improved substantially in recent years and management problems are much reduced.

Lateral move equipment moves through a field using one of several types of guidance options:

**Above-ground cable:** a tensioned cable extended adjacent to the travel path of the cart is used to guide the system. One or two arms extending from the cart have sensors touching the cable. These sensors mechanically pick up movement by the cart away or towards the cable and signal the movement system to adjust accordingly. The cable must be located and installed with great accuracy. Buried guidance is normally mounted in the middle of the machine regardless of cart location.

**Channel:** where the LM is supplied by a channel, sensor arms extending from the cart have skid plates touching the inside of the channel. These sensors pick up the mechanical movement of the cart away or towards the channel and signal the movement system to adjust accordingly. The channel must be concrete lined and located and formed with great accuracy.

**Small furrow:** a separate small V-shaped furrow is formed along the length of the travel path to suit guidance arms extending from the cart. The arms move in the furrow as the cart moves, mechanically sensing any misalignment of the cart. Furrow guidance may be located on any tower on the machine.

**GPS:** uses GPS sensors to determine deviation from the correct travel path. This requires the use of high resolution GPS units and careful programming of the travel path. GPS guidance eliminates maintenance issues associated with mechanical guidance options and may improve precision of lateral moves. In Australia, coastal areas seem to work well but further inland more satellite outages seem to occur. For the immediate future, GPS is more likely to be used for monitoring machine position rather than guidance.
Automation

Control panels vary in complexity depending on requirements. Where necessary, all functions can be manually controlled. Features that are commonly available include machine remote control using either computers or mobile phones with voice feedback and programs to apply varying amounts of water over different periods. It is possible to program the machines to stop where required or vary the application across the field. For lateral move machines, it is possible to progressively apply lighter amounts of water and then to reverse direction at the end of the field, applying increasingly larger amounts of water.

Pressure switches are commonly incorporated to stop pumps when pipes burst (that is, on low pressure) or to start the machine moving when water pressure builds up. Hydraulically driven machines often employ electric over hydraulic controls to perform the more complex tasks of automation. Automation is essential to take full advantage of the CPLMs’ capacities. While automation may increase the machine complexity, it can substantially reduce the time involved in management and provides the level of control required to maximise the return on investment.

Fertigation and Chemigation

Fertigation and chemigation using CPLMs can be conducted in two distinct ways. Chemical can be injected into the irrigation water in the main pipe for distribution through the emitters with the water. Products that can be distributed in the irrigation include fertilisers, herbicides, insecticides, and fungicides. Alternatively, chemigation can be conducted using a separate system of distribution pipes with spray heads suspended underneath the CPLM truss rods to enable the application of chemical with or without irrigation water. Fertigation is widely practiced by CPLM operators and is covered further in WATERpak Chapter 5.8.

Measuring the performance of CP & LM machines

The three most important measures of CPLM performance are application rate, uniformity of application and application efficiency. This section explains the importance of each measure and outlines the design and management factors that influence the relevant machine performance variable.

Application rate

Three measures of the application rate are important: the system capacity, the average application rate (AAR) and the instantaneous application rate (IAR). These measures differ primarily in the time scale being considered: system capacity measures are commonly reported as volumes applied per day or week, the average application rate reported as volumes per hour, and instantaneous rates reported as volumes per second.

System capacity: The system capacity of a CPLM machine is the average daily flow rate of water pumped by the machine divided by the area of that irrigated crop field. It is expressed in the units of millimetres per day, so that it can be directly compared with the peak crop evapotranspiration rate. Alternative units for system capacity would be in ML/ha × 10^2/day (that is, ML per hundreds of hectares per day). System capacity is the maximum possible rate at which the CPLM can apply water to the chosen area of irrigated field. It is not the amount of water that the machine applies per irrigation pass.
Dealers and manufacturers commonly use system capacity for their calculations and their assumption is that the pump is running for 24 hours a day, seven days a week, providing 168 hours a week pump running time.

The system capacity (in millimetres per day) is calculated by converting the CPLM’s pump flow rate into litres per day, and dividing by the irrigated field area in square metres. Remember, 1 litre over 1 square metre equals 1 millimetre depth of water applied. Alternately, growers can calculate the system capacity (mm/day) by taking the megalitres per day pumped onto the irrigated field and dividing by the irrigated area in hundreds of hectares.

System Capacity (mm/day) = \( \frac{\text{Average daily pump flow rate (L/day)}}{\text{Area Irrigated (m}^2)} \)

The design and management issues associated with the system capacity are often not well understood by Australian growers using these machines and account for many of their perceived failures. System capacity is discussed in further detail in the next section.

Average application rate: The average application rate (AAR) is the average depth of water applied to the irrigated field during the irrigation. The AAR is calculated by dividing the emitter flow rate (in litres per hour) by the wetted soil surface area (in square metres). The AAR is normally reported in millimetres applied per hour, to allow for a direct comparison with soil infiltration rates.

AAR is altered when emitter wetted area or flow rate is changed. The wetted area is affected by sprinkler height, wind, and sprinkler impact plate changes. Nozzle pressure, nozzle size and sprinkler spacing affect individual sprinkler flow rates.

The introduction of low-pressure fixed sprinkler plate technology in the 1960s and 1970s resulted in increases in AARs because the area wetted by the sprinklers was smaller than that with the previous higher-pressure sprinklers. However, the more recent development of rotators, wobblers, spinners and other moving plate sprinklers have resulted in a substantial decrease in AARs due to the larger throw and greater average droplet diameter of these emitters.

For centre pivot machines, the highest AAR is found at the outer end of the machine. AAR will always be greatest at the outer ends of centre pivots equipped with only one type of emitter and nozzle, as individual emitter flow rates increase in response to the larger annular area irrigated. The AAR of lateral move machines will be lower than the AAR at the outer ends of centre pivots. Individual emitter flow rates on a lateral move will be much smaller than an emitter located on the outer end of a centre pivot that has a similar irrigated area and managed system capacity.

Considerable research in the USA has been conducted upon the common mismatch of AAR and soil infiltration rates at the outer ends of centre pivot machines. For example, Scherer (1998) showed that sprinklers that throw to a radius of 10 metres, sited on the end of a 400 metre long centre pivot, produce average and peak application rates in the order of 40 and 50 mm/h, respectively. When these AARs are compared to the 5 mm/h average infiltration rates common for many clay soils, it is inevitable for the resulting excess water to be temporarily stored in surface roughness or run-off. This is supported by a range of work which suggests that the AAR associated with low pressure sprinklers on the outer ends of centre pivots will commonly exceed the infiltration rate of all soils except sands (for example, Kincaid et al. 2000; King and Kincaid 2001). Other options to reduce surface run-off under these conditions include retaining crop stubble, using spreader bars to increase separation between emitters and using long throw spray emitters.
**Instantaneous application rate:** The instantaneous application rate (IAR) describes the rate at which water is applied by an individual streamlet from an emitter head to a very small area of irrigated field (for example, hundredths of a square metre). The time scale under consideration for determination of IAR is in the range of seconds and the IAR is typically 1.3 to 1.5 times greater than the AAR (Kincaid et al. 2000). High IARs are commonly recorded where streamlets from static plate sprinklers impact upon a small portion of irrigated field during the stop cycle of electrically driven centre pivots. However, there will be zones of high IAR within the wetted area of every sprinkler pattern.

IARs under CPLMs are rarely measured in the field. However, the genesis of larger run-off issues is contained in this small area and time scale. Puddling of the soil surface begins from the impact of the streamlets, and is rapidly followed by soil surface sealing through the rearrangement of the destroyed soil crumbs. Most CPLMs in this country are equipped with rotating, spinning and oscillating plate sprinklers that overcome the high IAR by not having individual streamlets that apply water to any one point. Irrigator concern regarding droplet impact energy (Stillmunkes and James 1982) creating soil crusting issues during germination has led manufacturers to develop specific sprinklers to help germination.

**Uniformity of application**

Uniformity of application refers to how evenly the irrigation water is applied across the field. In fields not watered uniformly, some parts will be irrigated to the desired depth, while other parts will be either under- or over-irrigated. These non-uniformities lead to yield variation across the irrigated area, resulting in differences in economic return for different portions of the field (Solomon 1988). The factors that contribute to non-uniformity include:

- emitter spacing, nozzle operating pressure, and emitter configuration
- nozzle size and selection with location along machine
- nozzle height, angle and wear
- machine movement including step size and its consistency
- flow rate variations due to discontinuous end-gun operation, and variations in pump duty, and
- run-off from high application rates.

Large nozzle gun sprinklers, which are commonly positioned on the ends of CPLMs, are also often responsible for the poor uniformity performance of application (Molle 1999). Poor uniformity around wheel towers on CPLMs is also a common problem, as growers and distributors often employ inappropriate techniques to reduce wheel bogging, resulting in lower uniformity and application rates in the vicinity of the wheel towers.

As CPLMs do not irrigate all parts of the field at any one instant, they must apply the same depth of water along their travel path and machine length to irrigate uniformly. This requires a different evaluation methodology from that employed on static sprinkler systems. Measurements are commonly taken along one or two transects across their travel path. However, this always results in an underestimate of the uniformity, because no measure of the variation along the direction of travel is obtained.

To adequately determine uniformity across the whole field, monitoring is necessary along the full travel path of the machine.

While standards for testing the spatial uniformity are available (for example, ISO11595; ASAE S436) there is still some debate over the appropriateness of the methodology employed in these standards. The dependence of uniformity measures upon sampling spacings (for catch-can layouts) has been discussed by Smith and Black (1991). On the basis of sampling theory, they recommended that catch can spacings should be of the order of ¼ of the sprinkler spacing (Smith 1995). Bremond and Molle (1995) likewise analysed catch-can spacing and determined that assessment errors could be minimised and catch-can spacings maximised when 5 m spacings were used for CPLMs with sprinkler wetted diameters of 20 metres.

Two coefficients are commonly used to express the uniformity of irrigation systems – distribution uniformity (DU) and uniformity coefficient ($Cu$). The DU is an empirical index that is calculated as the ratio, expressed as a percentage, of the mean of the lowest one-quarter of applied depths and the mean of all applied depths:

$$DU (%) = \frac{x_{\text{lower quarter}}}{x} \times 100$$

where $x_{\text{lower quarter}}$ equals the mean of the lowest 25% of individual catch-can depths and $x$ equals the mean of all individual catch-can depths. The uniformity of application for solid set impact sprinklers has traditionally been considered
acceptable if the calculated DU is greater than 75%. However, Bremond and Molle (1995), Heermann (1991) and Yonts et al. (2000b) have suggested that DU should be greater than 90% for CPLMs to be considered to be performing well.

The Uniformity Coefficient (Cu) was first proposed by Christiansen (1942) and is defined as:

\[ Cu = 100 \left( 1 - \frac{M}{\bar{x}} \right) \]

where \( M \) is the mean absolute deviation of the applied water depths \( \bar{x} \) (or catch-can depths from sampling grid) and is given by:

\[ M = \frac{\sum |\bar{x}_i - \bar{x}|}{n} \]

where \( \bar{x} \) is the mean applied depth and \( n \) is the number of measurements. For systems that have a considerable variation in uniformity, there will be large variations from the mean and the coefficient will decrease. Solid set sprinkler systems that have a Cu less than 86% would typically be viewed as under-performing while CPLMs would be expected to have a Cu greater than 90% to be considered acceptable.

Heermann and Hein (1968) proposed a measure of application uniformity that should be used specifically for centre pivot machines. In this measure, the applied depths are weighted according to their radial position along the length of the machine, to allow for the different annular area represented by each depth. The modified Heermann and Hein (1968) coefficient of uniformity can be written as:

\[ Cu = 100 \left[ 1 - \frac{\sum S_i |\bar{D}_i - \bar{D}|}{\sum \bar{D}_i S_i} \right] \]

where \( \bar{D} \) is the applied water depth for one collector position, \( \bar{D} \) is the average applied water depth for all collectors, and \( S_i \) is the distance to equally spaced collectors.

Marek et al. (1986) and Bremond and Molle (1995) introduced other areal weighted uniformity coefficients specifically for centre pivot machines. Both of these methods use the square of the differences from the mean, rather than mean deviation as used by Heermann and Hein (1968). These methods emphasise any significant deviations from the mean and are useful in highlighting the poor performance of broken or blocked emitter nozzles.

A number of researchers (for example, Heermann 1994; Smith 2000) have also suggested that representing the irrigation variation using a cumulative irrigation depth distribution curve may better describe the performance of an irrigation system than the use of a simple coefficient.

Figure 5.5.13 summarises the \( Cu_{HH} \) for 22 recently evaluated centre pivot systems, most of which were less than 3 years old. Despite the fact that such systems should be expected to have high uniformity, the average \( Cu \) was 82% and only two of the systems achieved the benchmark uniformity of 90% mentioned above. Such results reinforce the importance of performance measurement, even for new systems.

![Figure 5.5.13 – Uniformity of 22 centre pivot systems. Few were able to reach the benchmark performance level of 90%. (Smith and Jessen, 2006)](image-url)
Application efficiency

The application efficiency \( E_a \) is a measure of the losses associated with applying water to a field. It is calculated as the ratio, expressed as a percentage, of the volume of irrigation water stored in the root zone divided by the volume of water supplied to the field inlet (IAA 1998). The loss mechanisms that decrease application efficiency for CPLMs include:

- sprinkler loss of fine water droplets
- evaporative losses from either the soil surface or plant surfaces
- run-off from the irrigated field; and
- deep drainage.

As with other forms of irrigation, run-off and deep drainage are most commonly associated with poor management and system operation. However, wind drift and evaporative losses are strongly influenced by emitter selection, nozzle size, operation pressures, and emitter location in relation to the crop canopy and weather conditions.

Evaporative losses are not well understood by Australian growers using irrigation. Drift and evaporation losses of sprinkler droplets (Figure 5.5.14) using a typical CPLM sprinkler configuration (nozzle pressure=138 kPa, nozzle diameter=4.7625 mm) are commonly reported as less than 5% and rarely greater than approximately 8%, even under extreme weather conditions (relative humidity = 10%, dry bulb temperature = 43°C, wind speed = 19 km/h, for example, Frost and Schwalen 1960). Similarly, evaporation losses from the crop canopy surfaces may be as small as 1% to 2% (New and Fipps 1995; Yonts et al. 2000a) and are commonly reported as less than 8% (Schneider and Howell 1999). Hence, moving the emitter into or below the crop canopy may not necessarily increase application efficiency dramatically and may result in greater run-off water losses due to the increased IAR associated with the smaller wetted area.

Figure 5.5.14. Illustration of the water loss pathways for LEPA and sprinkler application methods under CPLMs

Source: from Schneider 1999
Sprinkler evaporation is best calculated using equations for the transient transfer of heat to water vapour away from freely falling water droplets, as developed by Kinzer and Gunn and reported by Heermann and Kohl (1983). Further, Heermann and Kohl (1983) correctly state that not all canopy and soil evaporation should be considered a loss, as the evaporating water reduces the transpirative demand of the crop and decreases the crop water requirements, therefore fulfilling the primary function of irrigation; that is to supply water to the crop. This has been demonstrated under Australian conditions by Uddin et al. (2012) who measured the additional evaporation during sprinkler irrigation as well as the simultaneous reduction in crop transpiration (Figure 5.5.15).

Figure 5.5.15 – Additional Evaporation and reduced transpiration measured during sprinkler irrigation (Uddin et al. 2012)

This has also been supported by experimental data from an extensive energy balance experiment conducted in Texas (Thompson et al. 1997). The data from a lateral move irrigation machine, equipped in separate sections with both top of pipe impact sprinklers and grooved static plate sprinklers on droppers, records 0.053 mm and 0.055 mm of droplet evaporation for impact and static plate sprinkler, respectively. This represents less than 0.25% of the 25 mm irrigation applied. The conditions of the test day during the measured irrigation event included dry bulb temperatures of 31°C and average wind speeds of 7.5 m/s. Maximum droplet evaporation rates were 0.04 and 0.14 mm/hr for the impact and static plate sprinklers, respectively, during the test period.

Schneider (2000) records other work detailing plant canopy evaporation as typically less than 5%, but soil evaporation on bare earth where there is no beneficial gain will potentially lose up to 10 mm in the first day after irrigation with a fully wet soil surface.

In summary it can be stated that modern low pressure, static plate and moving plate sprinklers have application efficiencies up to 95%. LEPA socks and bubbler emitters have been found to have application efficiencies up to 98% where surface run-off is well controlled. However, up to 50% runoff has been found (Schneider, 2000) where LEPA systems are operated under adverse conditions without furrow dyking.
Designing the system capacity of CPLMs

System capacity is the most important design parameter for CPLM machines in the Australian cotton industry. Many machines installed in Australia in the past do not have a system capacity large enough to ensure cotton crop success. The problem of low system capacity has been the single greatest reason for the low uptake of CPLMs in Australia, and only if they can supply water onto irrigated cotton fields at a rate great enough to cater for peak crop evapotranspiration rates can they succeed in the Australian cotton industry.

The highly variable climate in which the Australian cotton industry operates means that timely and beneficial rainfall cannot be relied upon to help irrigation systems during peak crop water requirement. No benefit can then be allocated to rainfall supplementing irrigation during that period when the crop most requires water and is not included in any of the following analyses.

This discussion assumes that growers have an adequate volume of water allocated for the irrigated area underneath their CPLM. Understanding your water resources is important, and other authors in WATERpak have addressed this issue.

Calculating the system capacity of your CPLM

To calculate your system capacity, take the flow rate of water pumped by your CPLM installation and divide by the area of crop that the CPLM will cover in any one cotton season.

\[
\text{System Capacity (mm/day)} = \frac{\text{Average daily pump flow rate (L/day)}}{\text{Area Irrigated (m}^2)}
\]

Example 1: LM system capacity

A lateral move is capable of pumping 300 litres per second onto 180 ha in a day – what is the system capacity?

\[
\begin{align*}
\text{Volume applied (L/day)} & = 300 \text{ L/s} \times 60 \text{ s/min} \times 60 \text{ min/hour} \times 24 \text{ hours} \\
& = 25920000 \text{ L/day} \\
\text{Area irrigated (m}^2) & = 180 \text{ ha} \times 10000 \text{ m}^2/\text{ha} \\
& = 1800000 \text{ m}^2 \\
\text{System capacity (mm/day)} & = \frac{\text{volume applied (L/day)}}{\text{area irrigated (m}^2/\text{day})} \\
& = \frac{25920000 \text{ L/day}}{1800000 \text{ m}^2/\text{day}} \\
& = 14.4 \text{ L/m}^2 \\
& \approx 14.4 \text{ mm/day} \quad (\text{as } 1 \text{ L/m}^2 = 1 \text{ mm})
\end{align*}
\]

Alternatively, divide the CPLM flow rate in ML/day by the area in hundreds of hectares, that is, 25.92 ML/day divided by 1.8 hundred hectares equals a system capacity 14.4 mm/day.
Example 2: Large lateral move capacity

A large lateral move runs along a supply channel that is 6600 metres long. The overall length of the lateral move machine is 1008 metres and the length of irrigated field underneath the lateral move is 984 metres. The pump flow rate for this lateral move is 300 L/s or 25.92 ML/day. If two 800 metre long fields, back to back, are used to grow cotton in one season, then what is the system capacity?

Volume applied (L/day) = 300 L/s × 60 s/min × 60 min/hour × 24 hours
= 25 920 000 L/day

Area irrigated (m²) in a single cropping season = 984 m × 800 m × 2 fields
= 1 574 400 m²

System capacity (mm/day) = volume applied (L/day) ÷ area irrigated (m²/day)
= 25 920 000 L/day ÷ 1 574 400 m²/day
= 16.46 L/m²
≈ 16.5 mm/day (as 1 L/m² = 1 mm)

Example 3: CP system capacity

Calculate the system capacity of a 496 metre long centre pivot, that is, 10 × 48 m spans + 16 m overhang with a pump flow rate of 141 litres per second

Volume applied (L/day) = 141 L/s × 60 s/min × 60 min/hour × 24 hours
= 12 182 400 L/day

Area irrigated (m²) = π × radius²
Where, π = 3.14
radius = 496 m
Therefore, Area = 3.14 × 496 m × 496 m
= 772 490 m² or 77.249 ha

System capacity (mm/day) = volume applied (L/day) ÷ area irrigated (m²/day)
= 12 182 400 L/day ÷ 772 490 m²/day
= 15.77 L/m²
= 15.8 mm/day (as 1 L/m² = 1 mm)

Alternatively, the flow rate, 12.1824 ML/day divided by 0.77249 hundred hectares = 15.77 ML per hundred hectares per day = 15.77 mm/day.

This is how to calculate the system capacity of CPLMs. It is a very important design parameter and is the maximum possible flow rate the machine can apply onto the irrigated area. Remember this is not the amount of water applied per irrigation pass.
Managing CPLM system capacity

The system capacity is the maximum possible flow rate that the CPLM can apply to the area of an irrigated field. The system capacity of a CPLM is reduced considerably in the real world by the number of hours that the pump is turned off during any given irrigation cycle. The amount of time the pump is running during any irrigation cycle is called the pumping utilisation ratio (PUR).

The pumping utilisation ratio can be calculated from the average number of pumping hours per day divided by 24 (or divide the total hours of pumping over a 10-day period by 240, let’s say 204 ÷ 240 = 0.85). Remember to take into account the non-irrigating time necessary for any pesticide spraying with over-crop sprinklers and the dry travel time of the CPLM that you think that you may need.

System capacity is further reduced by losses that occur when the water travels from the nozzle on the machine into the crop root zone. This ratio of the water that actually makes it into the crop root zone divided by the total amount of pumped water is called the application efficiency (see earlier discussion). For LEPA systems, choose an application efficiency of 0.98, and for modern over-crop sprinkler systems choose a value of 0.95.

\[
\text{Managed System Capacity (mm/day)} = \text{Design System Capacity (mm/day)} \times E_a(\%) \times \text{PUR} (\%)
\]

As an example, a grower running a CPLM pump for 204 hours throughout a 10 day period during the peak crop water use period, using a well-tuned over-crop sprinkler system, would be able to irrigate at a rate of \(0.85 \times 0.95 = 0.81\) of the system capacity.

In a worst case scenario you might have a system capacity of 14 mm/day, but if the pump only ran for 0.75 of the time, even with a LEPA system, then on average 10.5 mm/day would be applied into the crop root zone.

Remember that these system capacity values have nothing whatsoever to do with the amount of water applied by the CPLMs during each irrigation pass. The amount of water that is applied per pass is governed by the pump flow rate and the amount of time that the machine takes to complete one irrigation pass of the complete irrigated area. Just as a constant flow rate boomspray operator would reduce speed to apply a greater amount of water to the field, so too is the average speed of a CPLM reduced to apply more water per pass.

For example, a centre pivot grower using good over-crop sprinklers with a system capacity of 14 mm/day, decided to set the machine speed so that the centre pivot took 2.5 days to irrigate the full circle, and then stop the machine for 0.5 day before restarting the machine. Under this management, the centre pivot would apply \(14 \text{ mm/day} \times 2.5 \text{ days/pass} \times 0.95 = 33.25\) mm for that irrigation.
Example 4: Managed system capacity

A large lateral move is designed with LEPA socks and a pump flow rate of 300 L/s with an irrigating width of 984 metres. The pump will run for 8.5 days out of 10 during peak crop evapotranspiration period. This downtime of 1.5 days includes time where the machine is being shifted across ends of fields or returning to the dry end of the field, or while aerially sprayed pesticides are being applied to the crop. The LEPA lateral move runs across two fields that are 900 metres long for a total cropped field length of 1800 metres. The managed system capacity (the average amount that the machine will apply into the crop root-zone per day) will be:

**Managed System Capacity**

\[
\text{Managed System Capacity} = \text{volume applied (L/day)} \times \text{pumping utilisation ratio} \times \text{application efficiency} \\
= \frac{300 \text{ L/s} \times 3600 \text{ s/h} \times 24 \text{ hrs/day} \times 0.85 \times 0.98}{984 \text{ m} \times 1800 \text{ m}} \\
= 12.19 \text{ L/m}^2 \\
= 12.2 \text{ mm/day}
\]

Alternatively, the 300 L/s equals 25.92 ML/day, and calculating how much water this will apply into the root zone per day over the 177.12 ha is given by 25.92 ML/day \times 0.85 \times 0.98 divided by 1.77 hundred hectares = 12.19 mm/day.

Choosing a system capacity for your CPLM

A common question raised by many cotton growers who are contemplating the installation of CPLMs is “What System Capacity should my CPLM have on my field?” The answer is that the system capacity should be sufficient to meet the crop water requirements for an extreme ET event.

**Step 1 – Determine local peak potential evapotranspiration**

A process for choosing a suggested CPLM system capacity has been developed utilising the evapotranspiration maps of Australia developed by the CRC for Catchment Hydrology and the Bureau of Meteorology under their technology transfer program (Wang et al., 2001) (see WATERpak chapter 2.8).

The point potential ET map for January (Figure 5.5.16) gives the period of greatest potential ET and also coincides with the period of greatest crop water requirement for cotton and most summer crops. If only winter crops are to be grown, a map for an appropriate month of the winter growing season could be used. Find your location on the map and determine the monthly ET by interpolating between the closest ET lines. Note that the mapped lines of equal potential evapotranspiration are in incremental steps of 30 mm per month.
Step 2(a) – Determine system capacity for cotton

For cotton crops, a calibration factor has been derived from the system capacities of CPLMs across the cotton industry which can be applied to the figure obtained from the January map. The calibration factor takes into account the conversion of the monthly average value to the more useful 3 day peak ETc value and assumes a pumping utilisation rate of 0.85 and the use of a LEPA system with an application efficiency of 0.98. If you wish to use other values for PUR and Ea, you may be able to adjust the value obtained from this step or alternatively follow the extended process below.

Once you have obtained your monthly figure from the map in Figure 5.5.16, divide this value by the cotton industry system capacity calibration factor of 21.5. The resulting number will be in millimetres per day, and is a starting point for grower’s decisions regarding the appropriate system capacity for their CPLM design. If growers are concerned about the particular value they calculate, consult appropriately skilled irrigation professionals.

For example, a cotton grower wishes to install a centre pivot at Bollon, which lies on Figure 5.5.16 at the 330 mark. Divide 330 by 21.5 and the suggested System Capacity is 15.3 mm/day. This would be the System Capacity a grower would install when the pumping utilisation ratio is 0.85 and the application efficiency is 0.98.

If you are growing cotton and this process suits your requirements, you may finish at this point.
Step 2(b) – Modify the ET estimate for other crops

Alternatively, crop coefficients may be used to estimate the peak crop water use from the point potential ET map. Crop coefficients ($K_c$) developed for use with the Penman-Monteith equation relate a range of crops to a standard reference crop as well as taking into account the stage of crop growth. They are discussed in more detail in WATERpak Chapter 2.1.

It should be noted that these crop coefficients were derived to suit the Penman-Monteith method and were NOT intended for use with other methods such as this one. However, for planning a centre pivot or lateral move system, experience has shown that this process gives a reasonable estimate in lieu of an alternative approach. If better information is available for your region and conditions, be sure to use this.

The relevant crop coefficient can be obtained from Table 5.5.3 or WATERpak Chapter 2.1. To determine the peak daily water use, take the monthly point potential value from the map, divide by the number of days in the month and multiply by the relevant crop coefficient. This will give the value that the managed system capacity will need to satisfy.

Step 3 – Determine system capacity for other crops

Once you have modified the map ET for your relevant crop, you will need to take account of your predicted pumping utilisation ratio and application efficiency to determine the system capacity required. If you are using the cotton calibration factor approach in Step 2(a), these factors have already been accounted for within the calibration factor. You should not mix the two methods.

By rearranging the formula for managed system capacity presented previously, we can determine the design system capacity as:

\[
\text{Design System Capacity} = \frac{\text{Managed System Capacity}}{\text{PUR}} \times \text{Ea}
\]

Because the managed system capacity needs to equal the peak crop water use, we can substitute this value in the equation above.

For Example:

Using the same example system as in Step 2(a) – a system for irrigation of cotton in Bollon, Qld. The peak ET month is January. From the map, point potential ET for Bollon is 330 mm. From Table 5.5.3, the crop coefficient for cotton for sub-humid regions is 1.2. The predicted pumping utilisation ratio is 0.85 and the system will use LEPA with a predicted application efficiency of 0.98

Daily ET for January = 330 ÷ 31 = 10.6 mm
Convert to peak crop water use = 10.6 × 1.2 = 12.8 mm/day
Determine design system capacity = 12.8 ÷ 0.85 ÷ 0.98 = 15.3 mm/day

Therefore, this system requires a design system capacity of 15.3 mm per day, the same as obtained using the cotton calibration factor in Step 2(a).
How does your design system capacity compare to a 3-day peak crop evapotranspiration rate?

In trying to understand whether or not a particular system capacity for a CPLM will adequately cater for the peak crop water requirements of a fully grown cotton crop, consider the evapotranspiration rates that would be likely to occur in any given crop growing season at a particular location.

If we were to undertake an analysis of the evapotranspiration for the St George region, the chances of having a 3-day average potential crop ET value greater than a certain size would look like the information detailed in Figure 5.5.17. When growers choose a certain system capacity for a CPLM installation in the St George region, for example, they are essentially choosing the number of days per year where the potential crop ET will be greater than the chosen system capacity of the CPLM installation. The nature of potential crop evapotranspiration is such that there is always the possibility in any year of a number of the days where high evaporation occurs.

The number of days per year where potential crop evapotranspiration is greater than the rate at which water can be supplied by the irrigation system needs to be reduced by choosing CPLM system capacities capable of handling these extremes. It does not matter how large a CPLM system capacity you choose, there will always be a day where peak crop evapotranspiration is greater.

Figure 5.5.17. Recurrence of 3-day peak crop evapotranspiration rates for the St George region

From the X-axis, consider the number of times per year where corresponding potential crop ET will be exceeded and then choose your own appropriate CPLM system capacity.

Understanding how many extreme 3-day peak crop evapotranspiration events per year will occur allows growers to determine their own level of risk in relation to their chosen CPLM system capacity. In effect, when growers choose their irrigation system capacity, they are choosing the level of risk that the machine will not be able to keep up with particularly high evaporative days. Growers who are not prepared to risk the possibility that their CPLM will ‘not keep up’ choose larger CPLM system capacities. The real consequences of choosing lower system capacities will be the reduction in the average amount of water held in the crop root zone as each passing day extracts on average more than the CPLM system capacity can supply. This does not necessarily mean crop failure, but rather the gradual decline in the readily available water supply for the crop and the potential for crop yield reduction.

For example, if the average 3-day peak crop evapotranspiration rate was 14.5 mm/day and the CPLM LEPA system capacity was 12 mm/day with continual operation, the average moisture content would decrease by 2.5 mm every day, and over 3 days this would create a total soil moisture deficit of 7.5 mm average across the entire field. This will not necessarily mean crop failure, but may lead to crop yield reduction.

A complete analysis of possible CPLMs system capacities and resulting irrigated crop performance in relation to regional peak crop potential evapotranspiration rates is only possible through the use of a crop model used for long-term climatic data in various growing regions with a wide range of system capacities.

Increased capital costs associated with larger CPLM system capacities do not necessarily increase in proportion to system capacity. For large lateral moves, whose upper size limit is currently controlled by the maximum flow rate of the largest pumps that manufacturers are prepared to place upon drive carts (typically a Cornell 10 RB @ 300 L/s), increasing the system capacity can be changed by decreasing the overall irrigated run length irrigated in any one season. This is a cost-effective and simple matter as no substantial change to the lateral move design is necessary.
However, costs could be incurred if changes are necessary to the field drainage network.

Increasing centre pivot system capacities involves changes in the nozzle set, imposing a very minor cost. More importantly, however, alterations in the pump and pipe diameters, both in the span and supply line, can have significant associated costs. If pumps and pipes are incorrectly designed, the lifetime running costs of the system can be greatly increased.

Remember that choosing larger system capacities for CPLMs does not mean that larger water volumes are applied to the crop. Choosing greater system capacities for CPLMs simply means that there is adequate capacity to cater for the peak crop water requirements of well-grown cotton when the crop requires it most. As one cotton grower saying goes ‘Change the things you can, and don’t worry about the rest’.

Recent purchases of large lateral moves in the cotton industry have all been with the largest pump flow rate possible for these machines. There currently exists an upper pump size limitation to the flow rates possible through the larger lateral moves. This is based upon the largest flow capacity from the Cornell 10 RB, a highly efficient double volute pump preferred by the small number of companies building larger lateral moves. Based upon this fact, a range of different field lengths have been calculated and are presented in Table 5.5.4.

### Table 5.5.4. Lateral move field lengths for various irrigating widths and system capacities with pump flow rates of 300 L/s, pump utilisation ratios 0.85 and 0.95 and an application efficiency ratio for LEPA of 0.98.

<table>
<thead>
<tr>
<th>Irrigating width under lateral move in metres</th>
<th>Pump utilisation ratio – expressed as no. of days per 10 days</th>
<th>Wetted total field length for system capacity of 12 mm/day</th>
<th>Wetted total field length for system capacity of 14 mm/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>700</td>
<td>8.5</td>
<td>2570</td>
<td>2200</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>2870</td>
<td>2460</td>
</tr>
<tr>
<td>750</td>
<td>8.5</td>
<td>2400</td>
<td>2050</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>2680</td>
<td>2300</td>
</tr>
<tr>
<td>800</td>
<td>8.5</td>
<td>2250</td>
<td>1920</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>2510</td>
<td>2150</td>
</tr>
<tr>
<td>850</td>
<td>8.5</td>
<td>2110</td>
<td>1810</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>2360</td>
<td>2020</td>
</tr>
<tr>
<td>900</td>
<td>8.5</td>
<td>2000</td>
<td>1710</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>2230</td>
<td>1910</td>
</tr>
<tr>
<td>950</td>
<td>8.5</td>
<td>1890</td>
<td>1620</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>2110</td>
<td>1810</td>
</tr>
</tbody>
</table>

### Running costs of CPLMs – implications of poor hydraulic design

One of the largest costs of ownership of CPLMs is the on-going pumping energy cost associated with supplying irrigation water through the machine. In the recent study of **CPLM operators in the QMDB**, 45% of growers were concerned with operating costs. Whilst energy costs are unavoidable when pumping irrigation water, about 70% of growers had an operating pressure that could be deemed to be excessive for the pressure regulators installed on their machines.

When designing CPLM systems, it is important to consider the potential energy costs of the system and minimise them wherever possible. This can be done by optimising the hydraulic design of the system, so that pressure losses are avoided and by ensuring the pump has been well matched to the system operating point and is not generating unnecessary pressure. Changing the operating point of an existing pump in an attempt to reduce pressure should be very carefully considered with appropriate professional advice as such alterations may impact pump efficiency and not result in the desired outcome.

From a design point of view, many growers who have purchased CPLMs in the past have not completely understood the implications of purchasing equipment with small pipe span diameters. Consequently, their overall cost of ownership was drastically increased when they purchased a slightly cheaper pipe span configuration. It is important to understand how increasing the overall upfront capital costs slightly can drastically reduce long-term ownership costs.
A present worth analysis of the long-term pumping energy costs of a large lateral move with four different configurations was conducted, as shown in Figure 5.5.18. This analysis translates the future costs of pumping energy involved with the lateral move into today’s dollars. The analysis was carried out over a 15-year lifetime, with 587 ML being applied per annum through the lateral move. Pumping energy costs were $1.43/ML/m head; an interest rate of 8% was used for this example. All spans available for this analysis were 48 metres long and two different diameter pipe spans were used as 6\(\frac{5}{8}\)” and 8\(\frac{5}{8}\)” nominal diameters. (Pipe diameter terminology is in keeping with current industry practice.)

The lowest cost option of the four different lateral move designs consists of 18 small diameter spans. The most expensive design consists of 14 spans of the larger diameter pipe spans. The economic and hydraulic modelling used to generate Figure 5.5.18 shows that increasing the number of spans with large pipes costs an additional 4%, but reduces the 15 year pumping energy costs to 80% of that from the lateral move with all small diameter pipe spans.

Similarly, when the analysis is conducted for a 9 span centre pivot, under the same economic modelling conditions and similar system capacity, the analysis shows that a 5% increase in capital costs can reduce the overall pumping energy costs to 60% of that of a centre pivot with all small diameter pipe spans (see Figure 5.5.19).
Practical management tips for CP & LMs

Crop growth and irrigation management

Management of crop growth under CPLMs can prove to be difficult for many who normally operate with furrow irrigated crops. For example, crops under these machines do not suffer from the waterlogging or large changes in soil moisture that can occur between furrow irrigations which often provide small amounts of crop stress and naturally prevent rank growth. Therefore crop and irrigation management under CPLMs is important to optimise crop growth and yield.

A significant advantage of CPLM systems is the flexibility to alter both the timing and the amount of water applied. This flexibility should be utilised by irrigation managers to give maximum benefit. Unfortunately, many growers are initially concerned about the ability of CPLM machines to apply enough water during periods of peak crop water requirement and therefore run the system with higher average soil moisture content than is necessary. This leads to an abundance of freely available water for the crop, possible rank growth and a reduced potential for rainfall capture.

A more effective strategy is to maintain the soil moisture below field capacity but above the normal furrow irrigation refill point to ensure the crop has access to ample water but to also allow maximum opportunity for rainfall capture (Figure 5.5.20). Regardless of the strategy used, crops are rarely saturated under CPLM irrigation and will be growing vigorously most of the time. Crop growth still needs to be monitored closely and the application of plant growth regulators, such as Mepiquat Chloride, may need a different approach to that used with furrow irrigation systems.

Figure 5.5.20 – Difference in soil moisture deficit under furrow irrigation and alternative CPLM irrigation scheduling strategies.

Irrigation management under CPLMs also requires operators to understand that the whole field does not have the same water status as is generally the case for furrow irrigation systems. It is more effective to view a field’s water status as always gradational (except after rain) and that irrigation applications are also gradational due to the time taken for the CPLM system to traverse the field. Soil variations within a field add to this challenge.

As discussed in chapter 3.2, consider a centre pivot system that is applying 30 mm of water to a 50 mm soil moisture deficit. The soil immediately in front of the machine (about to be irrigated) would have a 50mm deficit whilst the soil immediately behind the machine (just irrigated) would have a 20 mm deficit (Figure 5.5.21). Assuming uniform daily water use, a point on the opposite side of the circle would be half way between these extremes, with a deficit of 35 mm. Such considerations can become complicated, particularly for new users and particularly after rainfall events. The OVERSched tool was developed to help visualise these soil moisture gradients so that irrigation management can be improved.

Figure 5.5.21 - Visualisation of potential soil moisture gradient in a centre pivot field. One side of the machine has dry soil whilst the other side has moist soil.
The use of soil moisture probes is also important, especially because CPLMs are often the size of several traditional furrow irrigated fields. This increases the likelihood of several soil types being present under a single system. When combined with rainfall events and the soil moisture gradients naturally expected across CPLM fields, this can make for challenging scheduling decisions.

At least one probe per major soil type should be installed and at least two per field is recommended. For centre pivots, the soil directly in front of the machine is the most different in moisture content (dry) compared to the soil immediately behind (wet). For lateral moves, this may be true in the majority of the run, but the opposite is the case at the end when the machine is about to commence the return pass – the soil immediately in front is the wettest.

Probes should be spaced evenly around the circle, or evenly between the beginning and end of a lateral field (preferably with a probe at both the beginning and end and one towards the middle). This means that the information that they give today will be used to make scheduling decisions for 2, 3 or 4 days into the future.

Wheel track and wheel rut management

One of the most important issues any new grower faces in the first few years of owning and managing CPLMs relates to wheel rut and wheel track management. Few issues are more bothersome for a grower, but few are less discussed by dealers and manufacturers than the issue of wheel track and wheel rut management.

There are a number of things that growers can insist upon in the design of CPLMs that will lessen the anxiety many growers feel in relation to this troublesome issue:

- Boombacks upon wheel towers direct irrigated water to that part of the field behind the travelling machine, allowing the tower to run upon dry ground. Ensure that the boomback reaches a great enough distance behind the wheel tower to minimise the water thrown up on it.
- Use half-throw sprinklers on solid drops immediately around the towers to ensure water is not thrown directly into the ground, as is the case with soft hose droppers.
- Consider reducing nozzle sprinkler flow rates immediately adjacent to towers to 80% of their existing flow rates.
- Larger tyre and wheel sizes are more commonly installed on CPLMs today and many growers are successfully conducting trials where three and four wheels are driven inline upon the tower base, instead of the traditional two. Track and dreadnought options abound in the US.

A number of factors are important to remember when initially managing a new CPLM. As the first seasons pass, significant wheel track compaction levels rise and wheel rutting issues tend to decrease. This compaction is a significant help to the operation of your machine under saturated soil conditions and it is important to consider leaving it alone during deep ripping operations.

Germination

All growers using CPLMs should use sprinklers to germinate their crop, and it is essential that growers understand some of the ways that this can be successfully carried out.

The biggest difference when compared to furrow irrigation is the ability to plant the crop into dry soil and germinate with a number of light irrigation applications. Many growers are initially reluctant to plant on a bone dry soil profile for fear of being behind from the start (in terms of soil moisture) and not being able to “catch up”. However if there is adequate system capacity, this should not be a problem. The soil moisture store can be gradually built up over the early part of the season whilst the crop demand is much lower than the system capacity which, as previously discussed, has been designed to cope with peak crop water use.

This approach is one of the largest advantages that CPLMs have over furrow irrigation in terms of water savings, as CPLM fields do not require inefficient pre-irrigation and also have spare soil moisture storage available to capture early season rainfall. A number of light slow irrigations throughout the
germination period can also assist crops to move through soils prone to crusting.

Having suitable sprinklers is essential; the potential issues with high IAR static plate sprinklers and germination have been discussed previously. Growers using moving plate sprinklers may not need to have a separate setup for germination, but users of static plate sprinklers may find benefit from utilising a second nozzle set that reduces the total machine flow rate through the pump. This is sometimes called a dual nozzle pack and is one of the cheaper options that growers can employ to successfully apply water softly to freshly cultivated soils without inducing crusting and causing seedling emergence issues.

Note that this approach will require additional labour for manual switching of nozzles before and after germination. Users of LEPA emitters will also need to factor in a similar labour requirement as they switch from LEPA to sprinklers (possibly also with a reduced nozzle size) for germination.

Stubble retention is also likely to have advantages during germination as the retained stubble helps to hold the seedbed together, reduce crusting, protect seedlings and also improves infiltration both at germination and throughout the season.

**LEPA irrigation systems**

After germination and crop establishment, some growers employ LEPA systems to apply water throughout the rest of the crop life. When growers move to LEPA systems they need to remember that water is now being applied at much higher application rates than any soil is capable of retaining at the time of application. A critical part of the original LEPA system was to build a retention system into the soil before using the LEPA heads. This involves building small dams or dikes in the furrow between crop rows to capture the water applied at a very high rate. The original system developed in Texas was built for irrigation systems that are supplementary in nature and was only designed for machines with system capacities in the order of 5 to 7 mm/day. This means that while trying to use LEPA systems in Australia upon machines with system capacities of 14 mm/day, we are essentially using these systems at over twice their originally designed capacities. Growers need to ensure that while they are operating LEPA systems on CPLMs at these high system capacities that the soil being irrigated has the retention capacity in the form of significant cracking or soil surface roughness to hold water where it is placed. Alternatively, growers need to consider the correct implementation of dikes and small dams in alternate rows as part of the normal field preparation process for the use of LEPA irrigation systems.

**Ensuring longevity from your CPLM investment**

One of the simplest ways to ensure that CPLMs remain cost-effective is to ensure their longevity. Some of the greatest risks associated with the longevity of the valuable investment that you have made in the CPLM irrigation system come from the natural world. Provided below are a number of practical tips to ensure the longevity of your CPLM investment.

**Corrosion** – ensure that, if the water quality tests that your dealer has analysed prior to purchase suggest that the standard galvanised machine will be prone to corrosion, you invest in machines that are constructed of material that is resistant to corrosion. An additional 5% upfront investment in the capital cost of the machine can mean up to a five-fold increase in the life of the machine.

Ensure that, regardless of the water quality used in the machine, all water is drained from the lowest points of the spans: some span drain designs do not allow this, and other designs include automatic valves that have variable operational success. One alternative is to plumb this low span drain point out to a tee placed into the second or third sprinkler dropper. This overcomes both the tower and wheeltrack flooding at irrigation shutdown and ensures that there is no valve to become blocked by irrigation sediment.

The risk from overland flooding with CPLMs is minimal, except through flooded areas where fast moving water exists. Some growers install earthen berms (mounds of soil) raised above the flood-prone field level that allow growers to park the machine above the level of the floods. Gearboxes should be
drained and refilled with new oil after inundation and electric control panels professionally cleaned and checked by professionals if they become immersed.

A number of CPLMs have been damaged by violent windstorms over the history of their use in Australia. A number of practical techniques can be employed by growers to prevent and or lessen the damage. Anecdotal evidence from machine constructors on-site during a violent wind storm report that the machine developed a bouncing action which threatened to loosen truss rods and collapse the recently built spans. The action of the wind past the round main pipe span was inducing vortices which alternately forced the main pipe up and down, causing the whole span to develop a wild bouncing action. The action of the wind past the round main pipe span was inducing vortices which alternately forced the main pipe up and down, causing the whole span to develop a wild bouncing action. Purchasing low-profile towers for low growing crops means that the span intercepts lower general wind speeds closer to the ground, in any wind event. Some growers park their centre pivots so that the centre point is directed into the prevailing storm path. Other growers operate their pumps and fill their machines with water to increase the weight and reduce the risk of these machines being moved by wind. Another option is to employ tie-down points at the end of field or on access roads. These can consist of submerged earth anchors such as large buried concrete blocks, vertically placed railway iron or wooden piles placed at intervals equal to span spacings, which have cable or chain attached to tie down span towers.

Modern tower gearboxes contain gas expansion chambers (flexible rubber diaphragm enclosed within steel enclosures ) that allow for the expansion and contraction of the gases and liquids in the gearbox during heating and cooling, without creating differential pressure upon the axle seals. This design does not allow suction pressure to build up on the axle seals of the gearbox when it is cooled during sprinkler irrigation, thus preventing water being drawn into the gearbox to corrode drive trains. In any instance, ensure that sump plugs are regularly removed and water is drained from gearboxes. CPLM manufacturers specify gearbox oils that have properties allowing water to separate from oil and settle to the bottom of the gearbox.

Towable gearboxes are available in a number of different designs, with the older style having caused enormous difficulty for growers over the years. The original design contains a second set of bearings that are positioned outside the original axle of the gearbox. They are configured so on removing a single pin, the wheel hub disengages from the gearbox axle. This allows free rotation of the wheel during towing of the centre pivot from one site to another upon this secondary bearing system. Over time the pin and secondary bearings wear and allow movement of the wheel hub upon the gearbox axle, resulting in a failure of the gearbox drive train. More modern designs allow the worm gear to be physically disengaged from the bull gear in the gearbox, so that the wheel hub remains attached to the original gearbox drive axle. They do not use a secondary set of bearings within the drive-line.

Ensure that you flush the main span pipes on a regular basis, especially if you are using any surface water or groundwater bores that are pumping sand. This will ensure that excessive sediment weight is removed from the spans, particularly overhangs, where this material tends to accumulate and induce additional loading stresses. Corrosion that can occur underneath these saturated sediments upon the wall of galvanised pipes can lead to early pipe failure. Many growers install large valves upon the end of the overhang and last spans to allow higher water velocities to scour sediment from the pipe spans when the valve is opened.
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