Planning and Managing Centre Pivot and Linear Move Irrigation in the Southern Riverina

Adrian Smith and Sam North

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Finally, the authors would like to acknowledge the contribution played by the late Graham Barron, who was a passionate advocate for irrigators in the Southern Riverina during a career with NSW DPI which spanned 15 years. Graham instigated this project and was a project partner until his death in February 2007.
Executive Summary

The past few years has seen a rapid increase in the number of overhead irrigators being operated in southern NSW as part of a farmers' push to increase profitability through increased water use efficiency and accurate application.

There is little doubt that centre pivot and linear move (CP/LM) irrigation systems are capable of giving high returns per megalitre of water applied, but these high returns are only possible if crop agronomy and water management practices are of a high standard.

And while these higher returns per megalitre of applied water are possible, this comes at the expense of higher capital and operating costs.

It is important that irrigators contemplating the purchase of CP/LM systems are aware of the positives and negatives, the applicability of their soils and farming systems and their own preparedness (and ability) to accept and adopt a change to their irrigation management.

This manual has been developed to assist irrigators in the southern Riverina who are considering purchasing or who have purchased CP/LM irrigation systems.

It has been written specifically for winter cereal and lucerne growers in the irrigation districts of the southern Riverina with the aim of ensuring better decision making regarding the use of scarce irrigation and capital resources. The manual is divided into sections which cover planning, design, installation and operation and maintenance.
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1. Introduction

With increasing pressures to improve water use efficiency, plant productivity and farm profitability, questions continue to be raised concerning the future direction of irrigated agriculture in southern NSW.

The key question irrigators and policy makers should ask is a relatively simple one – is the irrigation system (or technique) best matched to the soils to be irrigated and the production systems implemented? If the answer is yes, then the system is best placed to satisfy ‘triple bottom line’ requirements.

CP/LM systems have an important role in the area. The significance of this role will be determined by answering the question above. While adopting such technology can certainly improve irrigation performance, CP/LM irrigation is not going to be the single ‘magic pill’ that cures the irrigation ills of this region. There are many factors which contribute to crop and farm performance – the irrigation system is but one.

There are examples in this area of poor machine performance or failure; the result of inappropriate machine design, poor site selection, unreasonable irrigator expectation and/or high running costs. And as one irrigator mentioned when questioned on the subject, the short answer was “a centre pivot is not going to instantly turn a poor irrigator into a good one”.

Irrigators considering adoption of CP/LM technology are encouraged to do the so-called ‘due diligence’ to determine if adoption of this technology suits them and their farm business. Look at your existing irrigation system – are there improvements that could be made to improve how it operates? Consult with industry experts, talk with experienced operators, talk with those who had machines, but no longer use them, and talk with designers and independent advisors.

The important message is to do your homework. This will put you in the best position to determine whether adoption of CP/LM is right for you. Happy irrigating!
2. What are Centre Pivot-Linear Move systems?

CP/LM systems are self-propelled irrigation systems. They apply water to a crop or pasture generally above the crop canopy.

Centre Pivots are anchored at one end, and rotate around a fixed central point. The water supply (typically from a hydrant) and power source are located at this fixed point. These machines can be permanently fixed to one site, or can be towable between a number of circles. Power sources for centre pivots are electric (mains) for electric and hydraulic machines, diesel gen-sets for electric machines or diesel hydraulic power packs for hydraulic machines.

Linear Moves (or Lateral Moves) are not anchored, but rather both ends of the machine move at a constant speed up and down a field. The pump and power source are located at one end (or in the middle) on a mobile cart. Water is supplied to the cart via lay flat hose, hard hose or open channel. The power supply can be diesel gen-sets for electric machines, diesel hydraulic power packs for hydraulic machines or mains (electric) via a dragged cable for electric and hydraulic machines (which are rare in Australia).

There is a third variation – the Centerliner or Pivoting Lateral which combines the attributes of a linear move and centre pivot machine. These require specially designed sprinkler packages which allow the machine to work in both modes of operation. They can be configured for operation from hydrants or open channels. They can be towable or site specific. With these 'pivoting lateral' machines, the machine operates as a linear move until it reaches the end of the field, and then pivots to do another irrigation run, producing what is referred to as a ‘racetrack’ irrigation field.

The main components of these systems are the self-supporting frame spans. Each span is supported by wheeled towers, which incorporate gearboxes, drive wheels and electric or hydraulic drive motors. The frame supports (or is incorporated with) water delivery pipes. Emitters (either sprinklers or low energy precision application (LEPA) fittings) are attached either directly to the main pipe, or suspended closer to the crop on rigid or flexible droppers.

The pump delivers a flow rate within a fixed range, and the machine speed determines the depth of water that is applied. Each span acts as an independent unit, so that the machine can be used over undulating ground. This is achieved through the use of flexible couplings joining each span. System alignment is achieved through micro switches, alignment levers and control equipment.
Figure 1. Typical components of a CP/LM machine (Source: Smith, A.)
3. Planning for Centre Pivot – Linear Move irrigation development

Irrigators considering upgrading or developing their irrigation infrastructure are encouraged to refer to the *Australian Code of practice for on-farm irrigation*, an irrigation code developed to provide guidelines for irrigators. Issues concerning planning, design, installation and commissioning, and operation and maintenance are discussed. The document can be found at: [www.irrigation.org.au](http://www.irrigation.org.au)

3.1. Strategic planning

The decision to install a new CP/LM system has the potential to significantly affect a farm business. Before proceeding, it is worthwhile spending time to consider such a decision in line with the long term strategic direction you have for your farm. This can be achieved by stepping through the following process:

- Describe your farm business.
- Identify your personal vision.
- Identify your farm business vision.
- Identify key issues in a SWOT (Strengths, Weakness, Opportunity and Threats) analysis. Develop strategies to capitalise on strengths and opportunities, and overcome weaknesses and threats. E.g. future direction of irrigated agriculture, effect of climate change, future for global commodity prices.
- Identify whether you have suitable soils and areas.
- Do some market research into the commodities you are considering growing.
- Ask yourself if you are willing (or able) to make changes to existing farming systems and understand new technology and techniques?

Ask the big questions – Do I want to be a farmer? Do I want to (continue to) be an irrigator? What commodities do I want to grow? What do I want to be doing in five, 10 or 15 years time? What are the benefits and downsides of CP/LM compared to other irrigation systems (including my current one)? Table 1 outlines some of these.

3.2. Resource Assessment

Collect information required for:

1. Economic and financial plan – use an estimated lifespan of 15 years;
2. Legal and regulatory issues (including environmental requirements);

3. Property issues;

4. Water supply and drainage issues;

5. Agronomic issues; and

6. Human resources.

Conduct an audit of your farm and do or update your whole farm plan. What are going to be the advantages (and disadvantages) of changing from your existing system? What are going to be the expected capital and operating costs compared with expected yields and returns of both your current or new irrigation systems? Are there other more pressing limitations to production (such as soil type, water security etc).

3.2.1. Identify natural features

- Identify remnant native vegetation; and

- Any legal requirements and obligations.

Natural obstacles concern mainly removal of trees and other native vegetation. Individuals need to contact relevant authorities (such as the Department of Environment and Climate Change, the Murray Catchment Management Authority or their local council) before any firm decisions on location are made. New ‘greenfield’ areas which may be brought into production may also have native grassland species, and again prior agency approval is required before any development is considered.

Often there will be compromises and/or trade-offs (planting new areas or managing existing native vegetation areas) required in order to gain approval for any native vegetation removal or clearing.

3.2.2. Identify man-made features

Man-made obstacles such as fences, shedding, ground-tanks and electricity lines need to be identified. Whilst these can be moved or altered, the practicality and the cost need to be factored into the overall system development cost.

Consider proximity to:

- Electric power supply; and

- Water source and actual/potential on-farm water storage site.
Figure 2. Plan ahead for CPLM machines. Proper planning is essential to avoid problems – running into trees is not recommended for CPLM machines! (Source: Montgomery, J.)
Table 1. Advantages and disadvantages of Centre Pivot – Linear Move systems (adapted from Finger 2005; Kelliher 2008).

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced variability</td>
<td>Cost</td>
</tr>
<tr>
<td>Reported application efficiencies for new well designed machines are generally in the 80–95% range, compared to 50–90% for surface irrigation systems.</td>
<td>Sprinkler systems have a relatively high capital cost compared to surface irrigation systems, unless substantial landforming is required for optimum performance of the surface system. Longer-term performance of the sprinkler system may be compromised by designs that reduce initial cost. Running costs can also be significant – and need to be evaluated during the design process.</td>
</tr>
<tr>
<td>Precise applications</td>
<td>Energy requirements</td>
</tr>
<tr>
<td>Able to apply a prescribed volume to match crop water requirements. Reduced opportunity for surface runoff or deep percolation if the system is designed to match soil infiltration characteristics. Ability to irrigate in winter with lower risk of waterlogging.</td>
<td>Pressurised irrigation systems require some form of energy source (electricity, diesel) to operate, increasing demands on power distribution networks.</td>
</tr>
<tr>
<td>Less landforming</td>
<td>Layout and soil considerations</td>
</tr>
<tr>
<td>Can work on rolling topography, variable soils and shallow soils that are not conducive to landforming. Will likely require some landforming for surface drainage of rainfall induced runoff. Essential to have adequate drainage and reuse capacity.</td>
<td>It can be difficult to match certain systems (i.e. centre pivots) to existing rectangular field layouts. Some vegetation may need to be removed for optimal performance of the sprinkler system. Soil variation under the one machine can lead to compromise – one soil, one machine.</td>
</tr>
<tr>
<td>Lower labour requirements</td>
<td>Water quality considerations</td>
</tr>
<tr>
<td>Can concentrate on irrigation scheduling and maintenance rather than ensuring application uniformity. Labour requirement is generally lower but depends on the system, the degree of automation of the machine and the supply system upstream of the machine, the design of the system and ongoing management and maintenance requirements.</td>
<td>Water may need to be filtered before use to prevent system blockages, with sediment-laden waters allowed to settle before use. Some issues with foliage damage from overhead application of salty water in arid environments. Poor water quality can affect longevity of irrigation infrastructure.</td>
</tr>
<tr>
<td>Improved agronomic conditions and reduced potential for deep drainage</td>
<td>Skills requirement</td>
</tr>
<tr>
<td>By ‘replacing’ water rather than refilling soil profiles, there is a lower risk of deep drainage, and soil temperatures and aeration status may be more favourable for plant growth/germination. Can leach salts efficiently using less water than surface systems.</td>
<td>Operation and maintenance of sprinkler irrigation systems will require different skills to surface irrigation systems.</td>
</tr>
<tr>
<td>Opportunities for fertigation</td>
<td>Considerations</td>
</tr>
<tr>
<td>Fertigation allows the targeted application of small quantities of nutrients, with a reasonable uniformity of application and less risk of nutrient losses. The irrigation system may also be used to apply herbicides and pesticides.</td>
<td>For the benefits in application efficiency, distribution uniformity, and reduction in labour to be realised, system design is critical. Compromising design to reduce the capital cost will transfer this cost into increased operating costs or difficulties. The system must be capable of delivering likely peak daily water requirement at a rate that does not exceed the infiltration rate of the soil, within the desired timeframe for operation.</td>
</tr>
<tr>
<td>Ability to sow on-time</td>
<td>Fitting in with other farm infrastructure</td>
</tr>
<tr>
<td>Able to either ‘pre-irrigate’ and sow directly into soil moisture, or dry sow crops and ‘water up’. Sowing crops on-time is one of the critical components in maximising yield potential in the Murray Valley (Fowler J., pers. comm.). Timely pre-watering also allows for knockdown herbicide application.</td>
<td>Fencing and access to paddocks will need to be reviewed when changing to a sprinkler irrigation system. The water supply to, and the drainage from, the system is another design consideration. Inability to have trees for shade and shelter in fields with these machines.</td>
</tr>
<tr>
<td>Considerations</td>
<td>Irrigation management</td>
</tr>
<tr>
<td>Importance of system design</td>
<td>There is no point installing a sprinkler irrigation system without also changing irrigation management. It is possible to flood irrigate with a centre pivot. Sophisticated methods of irrigation scheduling are required to gain most benefit from the sprinkler system.</td>
</tr>
</tbody>
</table>
3.2.3. Identify soil types

Some soils are more suited to CP/LM irrigation than others. It is important to understand the characteristics of the soils you are intending to develop, so that issues and limitations are fully understood before significant investment in CP/LM technology is realised.

Table 2 provides an overview of the generic soil suitability and applicability of the five main soils groups of the southern Riverina to CP/LM irrigation systems.

Apart from an understanding of general soil characteristics, it is essential that site specific information is collected and assessment made of the following:

- Conduct a soil survey to map soil management zones – for example use electro-magnetic (EM) technology;

- For each zone determine:
  - Soil water holding capacity;
  - Slaking and dispersion – slaking is not as big a problem with overhead systems compared with surface systems, but dispersive soils are not suited to overhead irrigation because of their very low infiltration rates;
  - any yield limiting factors:
    - Salinity;
    - Sodicity;
    - Acidity; and
    - Poor soil structure (e.g. compaction, hard pans, crusting).

Try to avoid soil type variation under a machine; it is best to have the one system irrigating the one soil type. If there is more than one soil type, irrigation and agronomy may be compromised and this will lower yields and performance.

There are systems being introduced to the Australian market which are capable of varying in-field application rates, but currently it is simpler to manage the one continuous soil type.
<table>
<thead>
<tr>
<th>Soil type</th>
<th>Suitable for CP/LM</th>
<th>Characteristics</th>
<th>Limitations</th>
<th>Best Management Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red brown earths (RBE)</td>
<td>Ideal</td>
<td>- Topsoil is sandy-loam to light clay loam overlying a clay subsoil. The lighter (coarser) textured topsoil is between 10-40 cm thick.</td>
<td>- No major limitations</td>
<td>Match irrigation application rates to soil intake rates and water holding capacity. Use EM surveys to identify management zones.</td>
</tr>
<tr>
<td>Sandhill soils (SS)</td>
<td>Yes</td>
<td>- Topsoil is loose sand greater than 15 cm deep.</td>
<td>- Undulating topography.</td>
<td>Improve soil moisture holding capacity and infiltration rates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Deep sands have loose sand to a depth of 2 m or greater, with no obvious subsoil.</td>
<td>- Low water holding capacity – requires frequent irrigation</td>
<td>o Reduce tillage and adopt conservation (direct drill) tillage techniques</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Shallow sands have shallower topsoil overlying a clay subsoil.</td>
<td>- High infiltration rates – potentially excessive deep drainage if over irrigated</td>
<td>o Retain stubbles and improve soil organic carbon</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Prone to erosion</td>
<td>o Control traffic (tramlines, GPS Steering) and remove stock</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Over irrigation (or rainfall after irrigation) can easily lead to nutrient leaching and to development of a perched watertable</td>
<td>o Apply gypsum to sodic soils (ESP &gt; 8)</td>
</tr>
<tr>
<td>Trans transitional red-brown earths (TRBE) – non sodic subsoil</td>
<td>Less suited</td>
<td>- Topsoils shallow and heavier textured than RBE</td>
<td>- Low infiltration of subsoils may increase risk of waterlogging</td>
<td>Reduce droplet impact energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Subsoils heavier textured than RBE and may be sodic</td>
<td>- Surface crust if topsoil is low in organic matter</td>
<td>o Use pressure regulators</td>
</tr>
<tr>
<td>Self-mulching clays (SMC)</td>
<td>Less suited</td>
<td>- Topsoil and subsoil has uniform, heavy clay texture</td>
<td>- Prone to compaction, especially when wet</td>
<td>o Use spinner plates and low pressure, large throw emitters</td>
</tr>
<tr>
<td></td>
<td>Require adoption of best management practice techniques</td>
<td>- Crumbly, well developed surface structure</td>
<td>- Problems with wheel tracking when wet</td>
<td>o Retain stubbles and plant cover to dissipate drop impact energy and reduce localised runoff and uneven wetting</td>
</tr>
<tr>
<td>Transitional red-brown earths (TRBE) – sodic subsoil</td>
<td>Poorly suited</td>
<td>- Topsoils shallow and heavier textured than RBE</td>
<td>- Infiltration and permeability of topsoil may be low, particularly if surface crustin occurs.</td>
<td>Schedule irrigations to avoid:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Subsoils heavier textured than RBE and may be sodic</td>
<td>- Low permeability of subsoils leading to increased risk of waterlogging</td>
<td>1. under-irrigation resulting in drought stress and reduced crop growth</td>
</tr>
<tr>
<td>Non self–mulching clays (NSMC)</td>
<td>No</td>
<td>- Topsoils shallow (&lt; 5 cm), poorly structured and usually dispersive</td>
<td>- Poor infiltration and permeability. Very low infiltration of subsoils leading to increased risk of waterlogging</td>
<td>2. over-irrigation resulting in deep drainage and reduced water efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Subsoils are dense, heavy clays.</td>
<td></td>
<td>Monitor soil water potential at 15 cm. As a general rule of thumb, most field crops and pastures in the southern Riverina should be irrigated when the water potential at 15 cm reaches -60 to -70 kPa.</td>
</tr>
</tbody>
</table>

Note: Some soil types may be modified and or improved to make them more suitable for overhead irrigation. Individuals should seek specialist advice before determining the suitability or otherwise of their particular soil to this type of irrigation system.
3.2.4. Map topography and identify issues

Once it is determined that soils are suitable for use in conjunction with CP/LM systems, the site of the proposed system then becomes important. Irrigators should identify:

- Site slope:
  - Excessive slope will result in runoff, lower infiltration and reduced yield (and profit);
  - Need for pressure regulators (significant variation in height will necessitate pressure regulators);
- Estimate pumping lift required:
  - From river, bore or surface systems – pumping from the different water sources will influence pumping costs.

Centre pivot machines can mechanically cope with quite steep slopes. Linear moves require generally flat fields or a steady constant rise or fall in the direction of travel to ensure steering performance is not compromised. Apart from mechanical considerations, excessive slope will have implications on water runoff (when combined with soil infiltration characteristics).

In the southern Riverina, typically the irrigation season is from August to May. If returns to capital are to be maximised for CP/LM systems, then an alternative source of irrigation water will be required outside the usual irrigation season to ensure adequate soil moisture levels for maximum crop growth and productivity (North et al 2008). Assuming no access to groundwater or river supply, it is highly recommended that irrigators considering CP/LM systems also have some form of on-farm water storage. Section 7.1.2 provides further detail in determining on-farm water storage requirements.

Any on-farm water storage should be located close to the site of the CP/LM on soil that has been assessed as being suitable from an engineering and water infiltration perspective. Expert advice should be sought. The cost of storage investigation and development and the cost of linking the water source to the CP/LM machine are additional cost factors.

- Waterlogging risk – drainage needs.
While there is a lower requirement for earthworks for CP/LM systems, there is still some. In general, ‘hills and hollows' should be levelled, particularly to reduce ponding after rainfall.

Natural drainage lines on the irrigated area should be connected to further facilitate drainage after rainfall events. It is important to connect the drainage from CP/LM areas to formal on-farm drainage (and reuse) systems to minimise the potential for poor quality runoff water to move off-farm, minimise water losses, and maximise the ability to reuse runoff at a later time.

The relatively low rainfall (particularly winter rainfall) experienced in the southern Riverina over the last ten years has seen the development of systems without enough consideration to in-field and off-field drainage. Drainage is essential to reduce waterlogging which lowers yields and profitability, and must be addressed during the design stage of the development.

### 3.2.5. Identify water supply and drainage issues

It is essential that irrigators understand both water quantity and quality issues and implications when considering adopting CP/LM systems.

- Determine water availability;
- Probability of occurrence of rainfall;
- Probability of occurrence of a given irrigation allocation;
- System supply capacity;
  - Flow rates through wheels and pumps; and
  - Extraction rate of groundwater.
- Need for on-farm storage; and
- Estimate conveyance and storage losses.

Section 5.2 of this document outlines how irrigators can make informed decisions about how much rainfall might be expected during the growing season (Figure 5 and Figure 6). Irrigators need to determine for themselves what level of risk they are prepared to accept for likely rainfall scenarios and develop their irrigation and cropping strategies from this. Irrigators also need to consider what the likely long-term trends in, and predictions of, rainfall are and again make their own informed decisions.
Irrigators also need to be aware of likely irrigation water availability, in terms of overall (over the irrigation period or season) and on a daily or event basis (flow rates). Figure 3 outlines the irrigation allocations that have been available in the Murray Irrigation Limited (MIL) area since 2002/03 (D. Ewington, pers. comm.). The average irrigation allocation over this period has been approximately 37%. The volume of irrigation water available has important implications in the financial viability of investing in CP/LM technology, as it relates to the ‘pay back’ period for the investment.

In addition to irrigation allocations within seasons, irrigators must also consider long-term scenarios regarding rainfall, runoff and irrigation water availability. Issues such as potential reductions in rainfall in catchment areas and the impacts this may have on irrigation water availability need to be considered. For example, work completed on behalf of the Murray-Darling Basin Commission (CSIRO, 2008) indicates there may be quite significant reductions to surface water availability and average water diversions in the Murray region by 2030. The full report can be found at: www.csiro.au

Irrigators need to avail themselves of the best information in order to gain an understanding of likely irrigation water availability. This will have important implications into investment decisions concerning irrigation systems.

![MIL Announced Allocation](image)

**Figure 3.** Annual water allocations to Murray Irrigation Limited customers 2002 to 2009. (Source: D. Ewington, pers. comm.)
- Determine supply water quality issues:
  - Electrical Conductivity, Sodium Adsorption Ratio and other issues such as specific ion toxicity;
  - Required leaching fraction if not using fresh water; and
  - Physical and biological contaminants – is filtration needed to minimise nozzle blockages and wear?

Specific information concerning irrigation water quality and suitability has been developed by the Australian and New Zealand Environment Conservation Council (ANZECC). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000) can be found at: [www.mincos.gov.au](http://www.mincos.gov.au)

Poor water quality will have an impact on the expected lifespan of the machine. Water quality should be analysed prior to design and costing, as poor water quality will have a significant impact on what type of pipes are chosen. Pipe material selection must be matched to the likely water quality.

Apart from impacts on machine performance, care also needs to be taken to ensure water quality will not have an impact on plant growth and performance. For example, high levels of Chloride in water applied to plant leaf surfaces can result in leaf ‘burning’. It is essential to regularly test water quality so that problems can be identified before crops are damaged.

Additionally, be aware of water quality impacts on soil. For example, the application of saline waters via overhead irrigation systems may lead to an increase in soil salinity levels as there is limited ability to ‘flush’ salts beyond the plant rootzone with overhead irrigation. Application of sodic waters can also negatively impact soil structure by increasing soil sodicity levels.

**Water quality - Chemical** - High concentrations of chemicals such as calcium, iron, acidity or alkalinity (pH) and salts can not only cause problems to the plants being irrigated, but also result in corrosion of the pipe systems supplying it.

For example, where the pH of water is above 7.6 or below 6.5, it is not recommended to use galvanised pipelines. There are a number of different types of pipelines which can be used, such as stainless steel, galvanised steel, poly coatings or fully suspended poly pipe. It is vital to fully understand the quality of the water to be used, be aware of its potential limitations (both to plants and the machine) and choose the appropriate pipe type accordingly.
Water quality - Biological and physical - Biological contaminants include weeds, floating trash, algae and slimes. The occurrence of these is more problematic for operators of linear move machines where water is drawn from open channels. These cause problems by blocking trash screens on suction pipes. It is essential that screens are installed on suction lines. Suction lines that become blocked significantly increase the pumping head, and therefore operating costs. Screens must be maintained regularly to ensure minimal blockages. Consider the use of back flushing screens to flush debris away from suction lines in open channel situations.

Sediments can also cause problems through blocked nozzles, increased nozzle wear, accumulation of sediments in spans (ultimately leading to corrosion) and additional weight in the spans causing load stresses and wheel ruts. Where water with high sediment loads is used, it is essential that regular flushing of pipelines is practised.

As a minimum, consider the use of automatic cleaning filters where surface water is being used, and manual clean ones where groundwater is used. Filters should also be designed to have minimal pressure loss, even when partially blocked, to ensure continued satisfactory operation.

The critical message is to take a representative water sample, get it analysed at an appropriate laboratory, and take the results to your supplier/manufacturer (and agronomist). They will then provide the right advice in terms of which type of pipe or pipelining will provide the best solution for your water quality conditions.

Fertigation - CP/LM machines can be used for the application of fertilisers (fertigation). If irrigators are considering this option, it is imperative that any application be as uniform as possible, so the design and operation of the CP/LM machines are critical.

Fertigation is quite common with CP/LM systems. Nitrogen is commonly applied this way, but many other nutrients can be applied provided they are in soluble or liquid formulations.

One of the biggest drawbacks to using CP/LM in this way is the potential for corrosion of pipelines. The best option is to specify non-corrosive components and/or linings when designing the machine. Alternatively, it is practical to under-sling a second spray line under the machine specifically for this purpose. It is essential that adequate flushing of pipelines is carried out at the completion of each application.

There are many issues which need to be considered before deciding to use CP/LM machines in this manner. These include:
• Integrating fertilising and irrigating from the one machine into farming operations. For example, the extra time required for the preparation, application, cleaning and flushing may disrupt the irrigation schedule;

• Ensuring that any fertilisers can be properly injected into the CP/LM, that they are appropriately mixed, and remain so during application;

• Ensuring there is no potential for back flow into the main water supply source;

• Ensuring correct and strict adherence to occupational health and safety requirements;

• Ensuring good calibration and maintenance of equipment; and

• Ensuring all fertilisers are adequately flushed from the machine at the end of the application.

However, if these and other issues can be addressed, there are definite benefits which can arise from the application of fertiliser in this way. These include timeliness, uniformity and precision of applications, reduced machinery movement, soil compaction and crop damage.

**NOTE:** Chemigation is the application of chemicals through CP/LM machines. There are currently no chemicals registered for this type of application in Australia. It is not to be practised.
4. Prepare a business plan

Once the factors outlined in Section 2 have been analysed and it appears that a CP/LM system is feasible, then it is essential that irrigators undertake the following (Harris et al, 2007):

1. Prepare a steady state (or current) profit analysis at the farm scale for the existing irrigation system (the 'without' scenario) and the one with the CP/LM investment (the 'with' scenario).

A steady state profit analysis is conducted to determine the annual operating profit for the 'without' and 'with' scenarios. The return on assets for each is then calculated using the annual operating profit and the value of assets (such as the land, improvements and machinery).

2. Undertake a financial analysis over the life of the investment for the 'with' and 'without' scenarios.

This analysis considers the cash flow of the business and includes debt repayments, drawings by the investor and taxation. The expected values and probabilities for yield and price are used to generate the nominal cash flows for the 'without' and 'with' scenarios. The likely variability in the cash flow outcomes is assessed by simulating the expected business cash flow using the range in yields and prices specified by each irrigator. This process enables a comparison of the variability in cumulative cash flow between the 'without' and 'with' scenarios over investment period to be made.

3. Complete an economic analysis to calculate and compare the Internal Rate of Return and the Net Present Values for the 'without' and 'with' scenarios.

This analysis examines the economic efficiency of the investment over the investment life. This analysis converts the future cash flows to their present cash equivalent, providing the decision maker with some of the information needed to make investment decisions between alternative farming systems. The internal rate of return (IRR) and the net present value (NPV) are then calculated for the investment in the CP/LMs. The IRR is a measure of the rate of return on an investment and is calculated in nominal terms before tax and interest has been deducted - it can be compared to the average unfranked dividends paid on shares over a similar investment period or the return before tax on long-term fixed investments. The NPV is the sum of discounted values of future income and costs associated with an investment.
4. Perform a marginal analysis to calculate the marginal return and payback period for the CP/LM investment.

In the marginal analysis only the capital invested in the project and the extra or additional returns generated by the capital investment are considered. This method of calculation allows the benefits arising from the project alone to be accurately identified. This analysis examines the cumulative cash flow associated with the investment and calculates pay-back period, the time taken for the investment to generate sufficient cash to cover the initial set up cost.

This approach simply allows a financial comparison between the cost of CP/LM technology against your existing (or alternate) irrigation systems, the system’s ability to meet plant water use requirements, and the expected yields achievable under different systems.

The 'with' and 'without' scenario analysis approach enables an assessment of the economic and financial performance of investment in CP/LM. It is not possible to make a 'rule-of-thumb' statement that the investment in CP/LM is or is not profitable, every farm business is different as are the water savings and yield benefits for the many crops that can be grown with these machines.

Yield and price risk, the extent of water savings, and the risk of water availability all need to be considered when deciding on investment in alternative irrigation systems. Other considerations include the availability of labour and the likely impact of changing energy costs on the viability of CP/LM investments.

This approach will not only identify the viability of the CP/LM investment but also the gaps in information that may exist and their importance. It will also be invaluable when seeking capital to fund the works. It will demonstrate to a financier whether the investment is sound or not.

Irrigators should consult with their financial advisors to assist in completing this assessment. To assist growers, Industry and Investment NSW (I&I NSW) has prepared a ‘net margin calculator’ which may be useful in preparing this economic analysis. This can be found at www.dpi.nsw.gov.au

Once this analysis has been completed, and the decision to invest in a CP/LM is made, growers should then seek as much information as they can to ensure the system is going to work. Suppliers, manufacturers and their representatives will be able to provide specific information on machine performance.
It is important during this initial planning stage that accurate information can be provided on both capital and operating costs. Importantly, seek clarification of various options for comparison.

It is essential to ask your supplier to do a comparison of capital versus operating costs over the life of a machine. The example below provides an excellent demonstration of the trade-offs between capital and running costs. The message is that a cheap, under-designed system is going to be expensive to operate.

The following example comes from the National Training Course ‘Improving Irrigation with pivots and laterals’ (CRC IF, 2007):

Example: Table 3 has an example of a centre pivot which is comprised of 10 spans, of 48 m in length. It has a lifespan of 15 years, and has 835 ML put through the machine annually. An interest rate of 7% is applied to the capital costs, and there are four different configurations possible, and two pipe sizes – either 6 5/8” (162 mm) and 8 5/8” (213 mm) diameter. The costs are based on actual capital and operating costs in 2003. What is the capital and operating costs of the four options over the life of the machine?

<table>
<thead>
<tr>
<th>Item</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine configuration</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>10 spans × 65/8”</td>
</tr>
<tr>
<td></td>
<td>7 spans × 65/8”</td>
</tr>
<tr>
<td>Capital costs ($)</td>
<td>189,000</td>
</tr>
<tr>
<td>Operating cost ($)</td>
<td>250,000</td>
</tr>
</tbody>
</table>


The message from this comparison was that a 6.3% increase in capital costs ($189,000 versus $201,000) resulted in a greater than 50% reduction in operating costs ($250,000 versus $121,000) over the lifetime running of the machine. Such a comparison becomes even more critical as the cost of energy is likely to increase over time.

One area that is often overlooked is the ability of your supplier to provide ongoing service, support and backup. Like any type of machine, problems are inevitable and it is important for peace of mind to know that service and parts are readily available.

An important source of information is from those growers/operators with considerable experience using CP/LM machines. They are an important source of practical information and will be able to provide valuable advice about the pros and cons of the
technology. Also, talk to those who either had machines and do not use them anymore, or who only use them intermittently, to understand what some of the drawbacks of the technology are.

I & I NSW Irrigation Officers and District Agronomists can also assist individual growers in making decisions about applicability of CP/LM systems to individual situations and can assist in conducting evaluations of machine performance.
5. Determine system requirements

After the resource assessments and economic feasibilities have been completed, the next most important phase is ensuring the CP/LM machine has enough capacity to meet plant water requirements and that water delivery rates do not exceed your soil's ability to take in water.

CP/LM systems apply small amounts of water when compared to surface irrigation systems and this necessitates more frequent irrigation. While this allows faster irrigation of a larger area, it also means there is a lower reliance on stored soil water to sustain the crop between irrigations and, consequently, a greater reliance on the irrigation system.

If plant available water is insufficient to meet plant demand, yield losses will occur. In extreme events, total crop loss may result. It is critical that CP/LM systems are designed with the capacity to supply the water requirement of the crops intended to be grown.

In order to do this, it is necessary to determine the following:

1. The peak crop water requirement likely to be experienced;

2. How much water per hectare will be needed to grow the desired crops; and

3. How much area can be irrigated with the available water supply (and the flow rate of the supply system).

The information contained within this section of the manual is by necessity somewhat detailed and there are a number of calculations involved. However, it is essential that irrigators considering CP/LM systems understand the various components which affect machine performance. This information, at the very least, will enable irrigators to ask the ‘right’ questions of their system designer(s).

5.1. Calculate the required design capacity

The maximum capacity of a CP/LM system to supply water to a crop is known as the design capacity. This is a function of the pump flow rate and the maximum area irrigated in one day:

\[
Design \ Capacity \ (\text{mm/day}) = \frac{pump \ flow \ rate \ (\text{ML/d}) \times 100}{irrigated \ area \ (ha)} \quad \text{Equation 1}
\]
The design capacity of any CP/LM system should be sufficient to supply the peak water requirement (which is a combination of peak crop growth and peak evaporation) of the intended crops.

Example: A centre pivot irrigator has a maximum pump flow rate of 60 litres per second and can irrigate an area of 40 ha per day. What is the design capacity of this machine?

60 Litres/second is equivalent to 5.2 ML/day. (60 L/s × 60 s/min × 60 min/hr × 24 hrs/day). Therefore, from Equation 1, the Design Capacity of the system is:

\[
\frac{(5.2 \text{ ML/d} \times 100)}{40 \text{ ha}} = \frac{520}{40} = 13 \text{ mm/day}
\]

The peak water requirement can be estimated from the evaporation record for a site by determining the daily potential crop evapotranspiration (ET\(_c\)) that has a given probability of exceedance. This has been done for winter and summer crops with full ground cover in the southern Riverina using the evaporation record at Deniliquin (Figure 4).

![Figure 4](image.jpg)

**Figure 4.** Average daily crop evapotranspiration. Cumulative frequency distributions displaying average daily evapotranspiration for crops with full ground cover in the southern Riverina for the spring (Sep-Nov) and summer (Dec-Feb) periods, based on 26 years (1978 to 2002) of pan evaporation data at Deniliquin. Dashed lines show ±95% confidence intervals.
It is up to irrigators to determine the level of risk they are prepared to accept, and then design their CP/LM machine accordingly. A probability level of 10% is recommended for designing CP/LM systems in the southern Riverina as it ensures that CP/LM systems:

1. Are not over-designed and thus unnecessarily expensive;
2. Have the capacity to supply crop water requirements for 90% of the peak growing season; and
3. Should be able to prevent any drought stress if used in conjunction with stored soil water to buffer extreme evaporation events (i.e. > 10 mm/day).

Figure 4 shows that for crops in the southern Riverina with full ground cover, the potential crop water requirement will be less than:

1. 7.7 ± 0.4 mm/day for 90% of the time in spring (September - November); and
2. 10.3 ± 0.4 mm/day for 90% of the time in summer (December – February).

90% of the peak growing season equates to 81 days in a 3-month (90 day) period, so there will be 9 days on average when daily ETc will exceed these values. The ± indicates what is called the 95% confidence limit. This allows us to say that, in 95% of years, daily crop evapotranspiration in the southern Riverina will be less than 8.1 mm/day (7.7mm + 0.4 mm) for 81 days out of 90 during spring; and less than 10.7 mm/day (10.3 mm + 0.4 mm) for 81 days out of 90 during summer.

We might presume from this that we can design CP/LM systems for summer crops with a capacity of 12.5 mm/day, as this well and truly exceeds the 10.7 mm/day of crop water use. However, this ignores the fact that CP/LM systems are not 100% efficient, nor do they operate 100% of the time.

Actual (or managed) system capacity is defined as the actual flow rate the CP/LM machine can deliver to the area being irrigated. Design capacity is the theoretical maximum volume that can be delivered, but is reduced in practice by the number of hours the pumping unit is turned off in any irrigation cycle (i.e. the pump utilisation ratio or PUR) and by losses incurred during irrigation (i.e. the application efficiency or AE – see section 6.1).

Actual (or managed) system capacity is calculated according to the following equation:

\[
\text{Actual System Capacity (mm/day)} = \text{design capacity} \times \text{PUR} \times \text{AE} \quad \text{Equation 2}
\]
Pumping utilisation ration (PUR) is the amount of time the pump is operating during any irrigation cycle. Pump ‘down time’ includes maintenance and breakdowns, requirements for in crop work (such as spraying or hay making) and machine ‘dry’ travel. It is important to consider the PUR over an extended time period, for example, a 10 day period, or for greater accuracy, the entire irrigation period. PUR will vary between CP/LM systems, seasons and crops.

PUR for towable pivots will be less than for fixed pivots because it takes time to “walk” the machine to the next circle as well as to disconnect it, move it and reconnect it.

Lucerne (and other crops cut for hay) will have a lower PUR because it cannot be irrigated between cutting and baling of the hay.

Example: The centre pivot identified previously has a Design Capacity of 13 mm/day. However, the machine operates only 8½ days out of every ten and has a well managed sprinkler package which has an application efficiency of 90% (or 0.9). What is the Actual System Capacity of this machine?

\[
\text{Design Capacity} = 13 \text{ mm/d} \\
\text{Pumping Utilisation Ratio} = 8.5 \text{ days} ÷ 10 \text{ days} \\
\quad = 8.5 ÷ 10 \\
\quad = 0.85 \\
\text{Application Efficiency} = 0.90
\]

Therefore, Actual System Capacity \( = 13 \text{ mm/d} \times 0.85 \times 0.90 \)

\( = 9.9 \text{ mm/day} \)

A design water requirement should be selected from Figure 4 that has an acceptable probability of being exceeded. This will be a trade-off between the cost of the CP/LM system and the likelihood of production losses because of drought stress. The Required System Capacity (mm/day) can then be found using the following equation:

\[
\text{Required system capacity} = \frac{\text{design water requirement (mm/day)}}{AE \times PUR}
\]

Equation 3

The examples following show the calculations needed to estimate the minimum Design Capacity required for lucerne irrigated using a fixed pivot and for winter cereal crops irrigated using a towable pivot irrigating three circles.
It is important to remember the Actual (or Managed) System Capacity value will not correspond to the amount of water applied by the machine during each irrigation pass. The amount applied per pass is governed by the pump flow rate (volume of water) and the amount of time it takes to complete a pass of the irrigation area (machine operating speed), both of which can be varied within set limits.

How do these equations and numbers relate to design of a CP/LM machine?

Example: Summer irrigated lucerne

A lucerne grower in the southern Riverina is using a fixed centre pivot. Typically, there are 10-12 days between pre and post-cut irrigations and 36 to 40 days between cuts over the period December to February. Allowing for other farm operations or delays in irrigation, the PUR for this lucerne grower is therefore approximately 0.65. AE is assumed to be 0.90.

A 10% level of exceedance is acceptable to the irrigator. This means the grower has accepted that 10% of the time during the December to February period, the machine will not be able to supply sufficient depth of water to keep up with plant demand. From Figure 4 a crop evapotranspiration of 10.3 mm/day is equalled or exceeded for 10% of the time in summer in the southern Riverina.

Using Equation 3, we can quickly determine the required system capacity of the centre pivot:

$$\text{Required system capacity} = \frac{\text{design water requirement}}{\text{PUR} \times \text{AE}} = \frac{10.3 \text{ mm/day}}{0.65 \times 0.90} = 17.6 \text{ mm/day}$$

So, in this case, the machine must have a significantly higher capacity (17.6 mm/d) than the design water requirement (10.3 mm/d).

In this instance, the irrigator should only consider a machine with a Design Capacity of approximately 18 mm/day.

Other options may be to accept a lower level of exceedance (i.e. more days where crop water use will exceed machine capacity, but declines in plant production are likely), or take measures to improve the PUR, or take measures to improve the AE, or a combination of all three.

A further option is to build a ‘buffer’ of moisture within the soil profile in the plant root zone. This may mean applying more water than the plants’ actually require (in practice this may mean starting irrigating earlier than the plant requires, and/or applying greater depths of water than the plant needs). This type of approach would require a soil type
with sufficient water holding capacity (i.e. not a sandhill sand) and the use of soil moisture monitoring equipment to accurately determine soil moisture levels at various soil depths.

Example: A towable centre pivot used to irrigate multiple circles

An important point to note when considering towable centre pivots used on multiple circles is the ‘irrigated area’ used to calculate the Actual System Capacity is the sum of all the areas of each circle that will be irrigated each season. This has significant implications in terms of a systems’ Design Capacity.

A towable centre pivot is used to irrigate three circles of winter crop of 40 ha each. In this case, the total irrigated area is 40 ha multiplied by three, or 120 ha.

The pump flow rate is 60 L/s, or 5.2 ML/day. The sprinkler package is a good one and the machine is well maintained, so the AE is 95%. It takes approximately four days to irrigate the three circles, so without allowing for some down-time for repairs and maintenance, the PUR is 75%.

The actual design capacity of this system is therefore:

\[
\text{Actual system capacity} = \frac{5.2 \text{ ML/day} \times 100}{120 \text{ ha}} \times 0.95 \times 0.75 = 3.1 \text{ mm/day}
\]

The soil has good water holding capacity and this is able to be used as a ‘buffer’ during periods of high demand in spring. The irrigator is prepared to accept a higher level of production risk and adopts the 30% level of exceedance which, from Figure 4, equates to a design water requirement of 6.0 mm/day.

\[
\text{Required system capacity} = \frac{6.0 \text{ mm/day}}{0.95 \times 0.75} = 8.4 \text{ mm/day}
\]

There is a considerable discrepancy between the actual (3.1 mm/day) and required system capacities (8.4 mm/day). From Figure 4, we see that daily crop water requirement will be greater than the capacity of the Centre Pivot to supply water to the crop (i.e. 3.1 mm/day) on 77% of days during spring in the southern Riverina. If two circles are irrigated, rather than three, and the PUR is increased to 85%, then the actual system capacity will be increased to:

\[
\text{Actual system capacity} = \frac{5.2 \text{ ML/day} \times 100}{80 \text{ ha}} \times 0.95 \times 0.85 = 5.2 \text{ mm/day}
\]
From Figure 4, we see this capacity (5.2 mm/day) will be exceeded on about 42% of days in spring. However, provided stored soil moisture is used and closely monitored and there are no breakdowns, it should be possible to run the system to deliver sufficient water to meet the total crop water demand in the two circles. The risk of crop water requirements not being met during critical growth stages in spring (e.g. flowering) is still high in this system.

If the pump flow rate was increased to 72 L/s (6.2 ML/day), then the actual system capacity when irrigating two circles would be increased to 6.3 mm/day. From Figure 4, there is a probability that this capacity will be exceeded on 25% of days in spring. This level of security to crop production would make this system far easier to manage.

There is good evidence to show that only one summer crop circle should be irrigated per Centre Pivot in the southern Riverina by machines with system capacities commonly being used.

If irrigating winter crops, a maximum of three circles with the one machine is suggested, while irrigating only two is more likely to obtain the best results. Obviously, this will depend on machine design capacity. Better decisions can also be made through the informed use of soil moisture monitoring and managing soil moisture as a ‘buffer’ where plant demand exceeds system capacity.

**5.2. Estimating total crop water requirement**

It is important that irrigators planning to invest in CP/LM technology determine how much water they can reliably access in order to determine how much crop they can grow for their investment.

It is possible to estimate the total water requirements of winter and summer crops using data from wheat and lucerne crops in the southern Riverina respectively using the following steps.

**For winter cereal crops** (e.g. wheat); select an achievable target yield: - yields of 6 and up to 7 t/ha are possible on non-sodic, non-dispersive soils under CP/LM systems in the southern Riverina. A more appropriate target yield for sodic (dispersive) soils is between 2 and 4 t/ha. Be realistic when setting target yields.

Estimate potential seasonal crop water requirement to grow this yield according to:

\[
\text{Crop water requirement (mm)} = \frac{\text{achievable yield (t/ha)} \times 1000}{20(\text{kg/ha/mm})} + 110(\text{mm}) \quad \text{Equation 4}
\]
Select a probability level for planning purposes that you are comfortable with and determine the amount of May-October rainfall that will be exceeded at this level of risk from Figure 5 below.

The depth of irrigation needed to meet plant water requirements with the selected probability is estimated from:

\[
\text{Maximum irrigation required in } x\% \text{ of years} = \text{crop water requirement} - \text{minimum May-Oct rainfall experienced in } x\% \text{ of years}
\]

**Figure 5.** Probability of equalling or exceeding a given amount of winter rainfall (May-October) at Deniliquin, NSW.

Example: An irrigator wishes to estimate the irrigation depth required to achieve a wheat yield of 6 t/ha crop in 4 years out of every 5 (i.e. 80% probability).

From Equation (4), the crop water requirement is:

\[
\text{Crop requirement (mm)} = 6 \text{ t/ha} \times 1,000 \div 20 \text{ kg/ha/mm} + 110 \text{ mm}
\]

\[
= (6,000 \div 20) + 110 \text{ mm}
\]

\[
= 300 + 110 \text{ mm}
\]

\[
= 410 \text{ mm (or 4.1 ML/ha)}
\]

From Figure 5, at least 160 mm (1.6 ML/ha) of rain will be received from May to October in 4 years out of 5 (80% probability).
The maximum irrigation requirement likely to be needed in 4 years out of 5 (80%) is:

Crop water requirement (mm) – rainfall (mm):

\[= 410 \text{ mm} - 160 \text{ mm}\]

\[= 250 \text{ mm}\]

In this instance, 250 mm or 2.5 ML/ha, of irrigation water will be needed to ensure the target yield (6 t/ha) can be achieved in 4 years out of 5.

**For summer crops** (e.g. lucerne); select an achievable target yield: - yields of 18 and up to 20 t/ha are possible on good soils under CP/LM systems in the southern Riverina. Again, be realistic when setting target yields.

Estimate potential annual crop water requirement to grow this yield according to:

\[
\text{Annual crop water requirement (mm)} = \frac{\text{achievable yield (t/ha)} \times 1000}{20(\text{kg/ha/mm})} + 200(\text{mm}) \quad \text{Equation 5}
\]

Select a probability level for planning purposes that you are comfortable with and determine the amount of annual May to April rainfall that will be exceeded at this level of risk.

The depth of irrigation needed to meet plant water requirements with the selected probability is estimated from:

*Maximum irrigation required in x% of years = crop water requirement – minimum annual rainfall experienced in x% of years*
Figure 6. Probability of equalling or exceeding a given amount of annual rainfall (May-April) at Deniliquin, NSW.

Example: An irrigator wishes to estimate the irrigation depth required to ensure a lucerne yield of 18 t/ha crop in 4 years out of every 5 (i.e. 80% probability).

From Equation (5), the crop water requirement is:

\[
\text{Crop requirement (mm)} = 18 \text{ t/ha} \times 1,000 \div 20 \text{ kg/ha/mm} + 200 \text{ mm}
\]

\[
= (18,000 \div 20) + 200 \text{ mm}
\]

\[
= 900 + 200 \text{ mm}
\]

\[
= 1,100 \text{ mm (or 11.0 ML/ha)}
\]

From Figure 5, at least 300 mm of rain will be received from May to April in 4 years out of 5 (80% probability)

The maximum irrigation requirement likely to be needed in 4 years out of 5 (80%) is:

\[
\text{Crop water requirement (mm) – rainfall (mm)}:
\]

\[
= 1,100 \text{ mm} – 300\text{mm}
\]

\[
= 800 \text{ mm}
\]

In this instance, 800 mm, or 8.0 ML/ha, of irrigation water will be needed to ensure the target yield (18 t/ha) can be achieved in 4 years out of 5.
5.3. Estimating the possible irrigated area

It is possible to estimate the area that can be irrigated using knowledge of likely irrigation allocations, rainfall and irrigation system capacity.

The possible irrigated area is estimated from the lesser of the following two calculations:

\[
\text{Maximum irrigable area} = \frac{\text{water available for irrigation (ML)}}{\text{crop irrigation requirement (ML/ha)}} \times AE
\]

Example: From the previous example, a wheat crop on good soils in the southern Riverina requires 410 mm/ha to achieve a yield of 6 t/ha. There is an 80% probability that 160 mm of rainfall will be received during the growing period. Therefore, 250 mm (or 2.5 ML/ha) needs to be supplied by irrigation. We also need to estimate application losses. In this case we will assume 10% losses, or 90% of the water pumped is actually supplied to the crop.

If 200 ML was available for irrigation, then the maximum area able to be irrigated is:

\[
= 200 \text{ ML} \div 2.5 \text{ ML/ha} \times 0.9
\]

\[
= 72 \text{ ha}
\]

\[
\text{Maximum irrigable area} = \frac{\text{daily pump flow rate (ML/day)} \times 100}{\text{design water requirement (mm/day)}} \times AE \times PUR
\]

Example: The soil has good water holding capacity so the farmer is prepared to accept an actual system capacity that has a 30% probability of being equalled or exceeded. From Figure 4, we see the design water requirement at this level of exceedance in spring is 6.0 mm/day. The CP/LM has a pump flow rate of 60 L/sec = 5.184 ML/day, and it is assumed AE = 0.9.

Therefore, maximum irrigable area is:

\[
= 5.184 \times 100 \div 6.0 \times 0.9 \times PUR
\]

\[
= 78 \text{ ha} \times PUR
\]

At this point, the farmer has a number of choices. He or she can install:

One machine to irrigate 72 ha (i.e. a 480 m long centre pivot = not recommended, or a linear move); two centre pivots to irrigate 72 ha (i.e. 36 ha each = 340 m long); or
One towable pivot to irrigate two 28 ha circles with a 300 m long machine (the PUR of this system will be 0.72, so the maximum irrigable area will only be 78 ha × 0.72 = 56 ha = 2 × 28 ha).

Calculating the possible irrigation area using these two methods takes into account the three limiting factors: system capacity, water quantity and flow rate. Once the two methods have been used, it is essential the smallest estimated area is used, as this incorporates the most limiting factor.
6. Design of Centre Pivot – Linear Move systems

It is essential that appropriate site, use and capacity information is included in any design. Take the time to ensure you get this right. Most suppliers have an ‘in-house’ design service that is included with the price of the machine. It is also a good idea to get an independent third party to review the design and the various options and limitations.

6.1. Design principles and measures

There are a number of important design principles which need to be considered when investigating CP/LM technology, of which the most important three are:

1. Match the actual (or managed) system capacity to plant water requirements.

2. Minimise the capital and long-term costs of the installation.

3. Minimise the operating costs of the machine over its lifetime.

Other important factors include:

- Ensure the system operates efficiently;
- Ensure the right type of pump, pipes and sprinklers are installed to achieve required flow rates and pressure levels;
- Ensure access for repairs and maintenance;
- Minimise hydraulic (friction) losses;
- Minimise energy costs;
- Ensure easy system operation;
- Ensure that structural requirements are met; and
- Ensure that any associated water delivery and drainage infrastructure (such as pipes, channels, gates, bore, valves, drains and culverts) are both correctly sized and located.

It is important that irrigators considering CP/LM understand some of the key measures which influence machine performance. These need to be factored into the system requirements at the design stage. Four of the most important measures are:
1. **Application Efficiency (AE)** is a measure of the actual water that ends up being available to the crop and is expressed as a % or fraction. It is equal to the volume of water delivered to the crop root zone divided by the total volume of water pumped. Losses include sprinkler losses of fine water droplets, evaporative losses from soil and plant surfaces, runoff and drainage below the root-zone. If runoff and deep drainage are negligible, then AE is primarily determined by sprinkler and evaporative losses. Provided this is the case, then typical AE for LEPA (Low Energy Precision Application) systems is 0.98, while for over crop sprinklers it is between 0.85 and 0.95. For well maintained systems, cumulative losses should be no more than 10-15% of the total water applied.

2. **Average Application Rate (AAR)** is the average depth of water applied to the irrigated field during the irrigation event and is usually expressed as mm/hr. It is calculated by dividing the emitter flow rate by the area of the sprinklers wetted footprint. It is essential that AAR be matched to soil infiltration rate during the design phase. For greater explanation on how ARR relates to soil types and management and design considerations, please refer to Appendix A.

3. **Instantaneous Application Rate (IAR)** is a measure of the rate at which water is applied by an individual emitter head to a very small area, and is usually expressed as L/sec or similar. It is typically 1.3-1.5 times greater than the AAR. Most CP/LM machines in Australia are equipped with rotating, spinning or oscillating plate sprinklers, which overcome the problems associated with high IAR by not having individual streamlets that apply water to any one point.

4. **Uniformity** of application is a measure of how evenly irrigation water is applied across the whole field and is expressed as a % or fraction. There is always going to be some variation, but the key is to manage it within acceptable limits. Good design, installation and maintenance are keys to this.

Apart from these system design specifications, irrigators need to consider other issues such as use of correct environmental practices for bunding fuel tanks, disposing of oils and filters, and soil retention works. Ensure occupational health and safety practices are carried out by considering safe access for personnel, signage, guards over hot and moving parts and how to handle confined spaces.

**6.2. Centre pivot or linear move?**

The choice of centre pivot or linear move is a combination of site suitability, cost and personal preference – do you want to farm in squares or circles?
Pivots generally have lower labour requirements than linear moves and are generally easier to manage, as dry ground is always in front of the machine. However, application rates on the outer spans can be extremely high and can result in poor infiltration, soil compaction and surface runoff. Pivots are generally suited to smaller areas. Because a circle only fills about 78% of a square, there is always the perception of ‘wasted’ land, but water is more often the limiting resource, not land, so this is generally not an issue for most farms in the Riverina.

Linear moves are suited to large areas and are usually constrained by the size of the pump mounted on the pump assembly. The maximum flow rate of large linear moves is about 300 L/sec. Above this requires large (above 10" or 248 mm) pipe diameters, which significantly increases the up-front capital cost, plus the wet weight of the machine will be significantly greater and this may cause operational problems.

Linear moves also require channels with high capacity to supply the machine and the water supply is therefore subject to potential evaporation and seepage losses. Additional channel maintenance may also need to be considered. Trash can accumulate more readily in open channels, making the use of trash screens and filters essential. There are many examples in this area of native summer grasses (such as windmill grass, Chloris truncata) being blown into channels and causing significant blockages to suction lines and channels. Such blockages will reduce pump operating efficiencies as well as flow rates supplied to the irrigated field. The PUR will also be reduced if pumping time is lost in order to unblock suction lines and remove debris from channels.

Figure 7. Lucerne under a centre pivot at Berrigan (Source: Barron, G., NSW DPI).
6.3. Span pipe sizes and operating costs

Because most machines are manufactured in the United States, imperial sizes are generally used in designs. However, there are a number of machines which are manufactured in Europe and these machines are generally built based on metric dimensions.

You must ensure span lengths fit in with your farming systems. Typically, span lengths of American designed systems vary from 113 ft (34.2 m) to 206 ft (62.4 m) and are commonly 168 ft (51.2 m). European designed machines typically have span lengths of 36m, 42m, 48m, 54m and 60m. Often the design of a machine will have different span lengths.

If you have, or will adopt, controlled traffic or precision farming practices, then you need to ensure your CP/LM – particularly the towers and emitters – fit in with your machinery. You must specify this to your supplier.

The range of pipe sizes varies from 5” (127 mm) to 10” (248 mm). The most common sizes among American designed machines are 65/8” (162 mm), 8” (197 mm) and 85/8” (213 mm). European manufactured pipes are typically 133 mm, 168 mm, 203 mm and 219 mm.

The use of different diameter pipes for the different spans is common design practice, as this balances capital cost and friction losses. The spans closest to the water supply
point often have a larger diameter than those further away. This is particularly so for centre pivots, where the inner ¾ of the machine uses about half the water, and the outer ¼ uses the other half.

It is also important to remember the selection of span lengths and pipe sizes should be tailored to the soils being irrigated. Long span lengths, for example, have more weight per square metre of wheel ground contact (of the tower) and this has implications for the potential development of wheel ruts and excessive soil compaction.

6.4. Sprinkler packages

Typically, sprinklers, nozzles and pressure regulators represent around 7% of the capital cost of a CP/LM but are responsible for 70% of irrigation performance.

The sprinkler package describes the height, location, spacing, size, type and discharge of each emitter (or sprinkler) as specified by the manufacturer. The aim is to use a package that does the job with as low a pressure as possible in order to minimise operating costs – 6, 10 and 15 psi packages are common (CRC IF, 2007).

There are generally two main groups of emitters – static plate and moving plate (Figure 9). The aim of emitters is to spread the water over as large an area as possible to minimise the instantaneous application rate, and to do it at as low an operating pressure as possible.

Static plates are about one-third the cost of moving plate sprinklers, have no moving parts, are simple and wear slowly and operate at low pressures.

Moving plate sprinklers are divided into three groups:

- Spinners (low pressure, fast rotation);
- Rotators (higher pressure, slow rotation); and
- Wobblers (medium to low pressure single stream, multi-path).

Moving plate sprinklers generally produce less streamlets with greater throw distances (and therefore larger wetted footprint and lower IAR) and a more controlled droplet range which is more resistant to wind throw and suited to application on finer textured (clay) soils. They also operate at low pressures, for example, Senninger I-Wobs™ or Nelson Nutators™ are specified at approximately 10 psi.
Flow rates through CP/LM machines have increased over recent years and this is the major reason for the general trend away from static plate sprinklers. Often, higher flow rates can result in the flooding of the standard static splash plate, causing banding or striping of water off the plate. However, mechanical sprinklers will alleviate this (York, pers. comm.).

Pressure regulators are fitted just above the sprinkler. They ensure all sprinklers are supplied with water at the same pressure in order to minimise variation in water application. The pressure above the pressure regulator on the last sprinkler should be 5-10 psi higher than that specified on the pressure regulator to ensure correct operation.

Soil type should also be considered when selecting the type of pressure regulator (and hence the operating pressure). Whilst lower operating pressures reduce running costs, it should also be noted the lower the pressure, the larger the droplet size and the greater its impact on the soil. A balance is required between reducing operating cost and maintaining soil surface structure and hence infiltration. Smaller droplets (and hence higher operating pressures) are likely to be needed on soils that slake and crust.
(e.g. transitional red-brown earths) or which are dispersive (e.g. non-self mulching clays).

A relatively recent development has been the so-called LEPA (Low Energy Precision Application) system. In this situation, a double ended ‘sock’ is placed over the end of the dropper hose, which then drags along the ground. All the nozzle flow is applied to a small area of soil and, as a consequence, the sock needs to discharge into a furrow to hold water, prevent runoff and allow time for infiltration. LEPA systems operate at very low pressures (6-10 psi) and generally have very high application efficiencies (up to 98%) because of very low evaporation. These systems are not well suited to germinating crops. They are better suited to row crop production and use with linear move machines.

Multi-mode bubbler units suspended 1-300 mm above the ground are a recent improvement to the LEPA system.

End guns are often fitted to CP/LM machines, particularly centre pivots, mainly because they increase the area irrigated. However, end guns have a large nozzle and require high pressure to propel the water. The irrigation pattern, application rate and uniformity are completely different to that applied under the centre pivot or linear move itself. Because of this, irrigators should seriously consider the practicality and usefulness of end guns. They require significant amounts of energy to operate and generally apply less water with poorer uniformity than the rest of the machine.

![Figure 10. Centre pivot fitted with spreader bars and an end gun (Source: Smith, A.).](image-url)
6.5. Installation and commissioning

It is essential that skilled and experienced operators install and commission your machine.

Once installed, it is advisable to undertake a system check to ensure its performance meets the design specifications. It is recommended that as part of the sale contract, the supplier should undertake an in-field audit and commissioning of the machine to ensure it is performing in accordance with the design specifications.

The audit should include (but is not limited to) an evaluation of the four key measures outlined in Section 6.1 (Application Efficiency, Average Application Rate, Instantaneous Application Rate and Distribution Uniformity), as well as the other factors identified in Table 5.
7. Operation and maintenance of Centre Pivot – Linear Move systems

In order to economically justify the expense of installing CP/LM systems, it is essential that crop performance is maximised, relative to the inputs invested in producing the crop. To meet these outcomes, a range of agronomic and physical factors must be well understood and managed accordingly.

7.1. Minimising production costs

Investment in CP/LM technology can be capital intensive. Both up-front and ongoing operating costs need to be considered.

7.1.1. Power source

An important decision when considering capital costs is the power source for operating these machines; electricity or diesel. There are likely benefits in establishing CP/LM with electricity. However, it is essential the capital cost of getting electricity to the site is considered in the overall development cost. It is also important to consult with your electricity retailer to ensure there is adequate capacity in the electricity system to operate your machine.

It is important to consider a likely rise in the cost of energy in the future. Any increase in energy use efficiency or saving in energy cost is therefore likely to become more important into the future.

As the length (and therefore the irrigated area) of a CP/LM machine increases, the capital cost per hectare generally decreases. However, the increased cost of operation due to friction can make large system expensive to operate. Friction is the main contributor to the running costs of CP/LM systems. The cost of overcoming friction (i.e. pumping costs) must be determined. In reducing friction costs, pipe size will likely increase (or flow rates decrease, decreasing the area able to be irrigated), which will increase capital cost.

In your discussions with the supplier/designer of your CP/LM system, it is essential that both capital and running cost options are discussed, and estimates provided for both on the expected lifetime of the machine (at least 15 years). It is important that individuals consider alternative pipe sizes, application rates and pump sizes during the planning stage, to ensure the most appropriate decision is made based on individual circumstances and requirements.
7.1.2. On-farm storage and drainage

A further possible component in up-front capital investment may be the construction of on-farm water storage.

This is particularly the case if you are located within an irrigation scheme with no access to ‘out of irrigation season’ irrigation water. In order to maximise yields of winter crops, it is highly likely that irrigation will be required at times when water is not available from the supply system (for example in late autumn, winter and early spring).

On-farm storage may also be necessary where irrigators have strict or only once daily ‘start up’ and ‘shut off’ times from their irrigation supply authority. Because of the nature of CP/LM systems, it is essential that no limitations are placed on the ability to supply the required volume of water to the field.

As mentioned in Section 3.2.4, drainage is also required, both in field to remove water (particularly excess rainfall), and off field to direct water from the field to a formal drainage and reuse site. Apart from the management benefits and flexibility such systems provide, it is also necessary in some areas to meet environmental guidelines.

In the southern Riverina, it is almost essential that some form of on-farm water storage (and drainage system) is developed in conjunction with a CP/LM system. This cost must therefore be factored into the overall development cost.

Table 4 provides a guide to how much water storage is required based on various areas to be irrigated and depths (or number) of irrigation water applied.

<table>
<thead>
<tr>
<th>Depth of water (mm) applied</th>
<th>Area irrigated (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>24</td>
<td>6</td>
</tr>
<tr>
<td>36</td>
<td>9</td>
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<td>50</td>
<td>13</td>
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<tr>
<td>100</td>
<td>26</td>
</tr>
<tr>
<td>200</td>
<td>42</td>
</tr>
<tr>
<td>300</td>
<td>78</td>
</tr>
</tbody>
</table>

Note: These required volumes assume no storage losses (such as leakage or evaporation), and no transmission losses from the storage to the CP/LM.
The question each grower needs to then ask is how much storage is enough?

The volume of storage needed to irrigate a winter crop through to the end of flowering without suffering drought stress in 4 years out of 5 (80% of years) can be estimated.

If the crop is sown during the recommended sowing window, wheat in the southern Riverina should have finished flowering by the end of the first week of October. To avoid water stress in the period from sowing (early May) to the end of flowering, wheat in the southern Riverina will require approximately 250 mm of water (Figure 11).

![Figure 11](image.png)

**Figure 11.** Average growing season crop water requirement. Average potential crop water requirement during the growing season for wheat sown on May 9th at Deniliquin, based on average $ET_o$ and local crop factors. The dashed line indicates the depth of water (i.e. 250 mm) required to grow the crop through to flowering in early October, without incurring water stress.

Analysis of the long-term rainfall record shows that at least 100 mm of rainfall can be expected in 4 years out of 5 (i.e. 80% of years) at Deniliquin during the period May to September inclusive (Figure 5). Assuming the soil at sowing is dry and the total crop water requirement from sowing to flowering is supplied solely by rainfall, then the irrigation volume required in 80% of years is 150 mm, or 1.5 ML/ha.

If it is assumed there is no irrigation water available during this period, then the full amount (1.5 ML/ha of crop area) will need to be stored on-farm.
If a centre pivot is used to irrigate two 40 ha circles (i.e. 80 ha), then the storage required to avoid drought stress in the period from sowing to end of flowering in 80% of years is 120 ML (80 ha × 1.5 ML/ha).

It should be highlighted that this is considered a very conservative estimate (i.e. “low risk strategy”) as it is based on a relatively high rainfall probability (i.e. 80%) and it is presumed that no off-farm irrigation supply will be available until quite late into spring.

A more typical scenario may be to consider median May to September rainfall and delivery of channel water in early September. Figure 11 shows that wheat requires 150 mm to avoid drought stress up to early September. From Figure 12 we can see that at least 150 mm of rainfall can be expected in the same period with a 50% probability (i.e. 1 year in 2). Therefore, if planning is based on this level of risk, then it might be presumed that on-farm water storage is unnecessary.

A further scenario may be that the irrigator is not prepared to accept this level of risk and wants to be sure he has water for 4 years in every 5 (or 80%). In this case, approximately 100 mm of rainfall is received (Figure 12), resulting in a rainfall deficit of 50 mm (150 mm plant requirement minus 100 mm of rainfall).
Under this scenario, 50 mm/ha (or 0.5 ML/ha of crop area) of irrigation water should be stored on-farm to minimise production losses. The 80 ha under the two centre pivot circles would need 40 ML of water to be stored on-farm.

The level of risk acceptable to an individual irrigator, the area under the CP/LM system, the timing of rainfall events and the ‘start up’ time of the irrigation season (combined with opening allocation announcements) all need to be considered in determining the volume of on-farm storage required. This storage requirement also assumes no capture of rainfall runoff on the farm, or additional storage requirements required by environmental licensing.

It should be noted that a major drawback of CP/LM systems is their comparatively high capital cost and its depreciation compared to surface systems, so a greater reliability of supply is needed to ensure a sufficient return to capital over the lifetime of the investment.

7.1.3. Reducing pumping costs

To reduce energy use, and hence operating cost, irrigators must either reduce the kiloWatt-hours (kWhr) required to pump each megalitre, or reduce the number of megalitres pumped (which will reduce crop yields and hence reduce net returns per ML). To reduce kWhr/ML, irrigators need to reduce the pressure required by their irrigation system or improve the operating efficiency of their pump.

To reduce the volume pumped per year, irrigators might consider some or all of the following:

1. Reduce the irrigated area;

2. Reduce crop water use (ETc) – schedule irrigations; deficit irrigate (this is not suited to all crops); grow crops when plant water use efficiency (WUE) is highest (i.e. when relative humidity is high, which effectively means winter crops);

3. Reduce the leaching ratio – use irrigation to supplement winter rainfall; use better quality water (i.e. shandy bore water); grow salt-tolerant crops;

4. Increase annual effective rainfall – use irrigation to supplement winter rainfall; and

5. Increase irrigation efficiency.
Increasing pump flow rate reduces pumping time but also increases the horsepower requirement. Theoretically, the flow rate does not affect energy use. However, increasing pump flow rate will tend to increase the total power bill for a number of reasons, including:

- Larger pumps cost more;
- Larger pumps require more demand charges if electric;
- Larger initial cost on main lines; and
- Greater friction losses (i.e. higher head).

The last, and perhaps easiest, way of reducing energy costs is to reduce the unit cost of the energy source. Irrigators might consider the following:

1. If the pump is electric, ensure you are on the right rate/tariff schedule. This can make a huge difference to the average cost per kiloWatt-hour.

2. If you are using diesel, check that your ‘economies of scale’ are correct. That is, do you have the appropriate amount of on-farm fuel storage? Possibly, with more fuel storage you could negotiate a lower delivered price. Obviously the cost of increased fuel storage must be compared to any fuel cost savings.

If you are a large consumer of energy (individually or as part of a group), whether it be diesel or electricity, you are in a good position to negotiate with suppliers to secure the most competitive price. If buying in bulk, check to see if a more accurate prediction of when and how much energy you will need can help in negotiating a lower price. There are consultants available who can help you develop a ‘load profile’ for individual machines.

7.1.4. Other methods to reduce operating costs

Apart from those methods outlined to reduce pumping costs, individuals may also consider the following to further reduce operating costs:

1. Reduce conveyance system losses – site channels and storages on non-leaky soils (EM survey and soil analysis), compact or line earthen channels and storages; keep channels, drains and storages clean and weed-free; reduce the amount of time water is in the conveyance system (to reduce evaporative losses); only store water during the winter period when evaporative losses are low; and
2. Reduce evaporative losses – direct drill; retain stubbles; sow crops/varieties at a rate to ensure quick ground cover/canopy closure.

7.2. Maximising yield potential

As outlined previously, adequate soil investigations are essential in the planning stage to ensure that soil type is not going to limit production. If soil type is seen as a significant impediment to plant production, either invest to improve your soil (if it is technically and economically feasible to do so), or do not invest in a CP/LM system.

7.2.1. Irrigation scheduling

Irrigators need to determine the best time to irrigate and how much water to use so that crops can be produced as efficiently as possible. We need to determine crop water requirements and manage the water to effectively meet these requirements.

An irrigation schedule tells us when we need to irrigate crops, as well as how much we need to apply. Traditionally, the surface irrigation systems used in this area have had limited opportunity to control how much water is applied. Adoption of CP/LM technology provides the opportunity to accurately match water requirements to application rates.

There are three ways in which an irrigation schedule can be determined, using:

1. Plant based methods – such as simply looking at the plant (to observe wilting) or more sophisticated methods such as measuring plant sap flow, or plant temperature;

2. Weather based methods – using evaporation rates, crop factors and rainfall, and determining plant root depths and the soils readily available water; or

3. Soil based methods – there are three options available, with the two most relevant being volumetric methods where the actual amount of water in the soil is calculated, or tension methods where the ‘tension’ reflects how much effort or energy the plant needs to use to extract water held by the soil.

Each method has its benefits and limitations and different levels of complexity and cost. Additionally, there are various methods and equipment which can be used to measure and predict soil moisture use, plant requirements and, importantly, when next (and how much) to irrigate.

North et al. (2008) used soil based methods to determine soil moisture and plant water use as part of their evaluation of centre pivot irrigation in the Murray Irrigation Districts. Gypsum blocks (WaterMark™ sensors) were used to measure soil tension (these
devices measure negative pressure, or suction). They concluded that a soil water potential of -60 kPa at 15 cm depth appeared to be a universal and simple indicator of when to irrigate crops for maximum yield under CP/LM systems in the Murray Irrigation Districts, irrespective of soil type.

Irrigating with pressurised systems is different from surface irrigating and a different mindset must be adopted if using CP/LM. It is important to remember that limited amounts of water can be applied with these systems. If you start irrigating too late (too dry), or try and stretch out the time between irrigation events, then it may become very difficult to ‘catch up’ to meet the crops’ water requirement and, if this occurs, plant growth and yield will be reduced.

At least for the first three years of a new CP/LM system, it is strongly recommended that irrigators adopt some form of soil moisture monitoring to determine how deep each irrigation is wetting the soil and whether under or over irrigation is occurring. Irrigation scheduling using weather data to forecast ET and crop water demand, combined with soil sensors to determine irrigation timing and amount is recommended for all users of CP/LM systems in the southern Riverina.

Figure 13. Some form of soil moisture monitoring is essential with CP/LM irrigation (Source: North, S.).
7.2.2. Crop agronomy

To achieve the yields required to make the purchase of CP/LM technology profitable, high standards of crop agronomy must be implemented. Without the adoption of good in-crop agronomy, such as meeting nutrient requirements, pest and disease management and weed control, then high yields and good returns will not be achieved, irrespective of the irrigation system. High levels of crop management (and irrigation management) are required to maximise the opportunity that CP/LM technology offers.

It is recommended that producers adopt best management practice guidelines. Programs such as the I & I NSW Crop Check Management Guides ensure maximum crop yield. Adoption of minimum till, direct drilling and controlled traffic technology will improve soil infiltration and moisture holding ability, so more water will get into the soil to fill a larger “soil reservoir”. This can be particularly important at the outer end of centre pivots, where application rates may exceed the instantaneous infiltration rates of the soil being irrigated.

7.3. Operational issues

7.3.1. Wheel rutting and bogging

Wheel ruts and bogging can be significant problems, particularly on ‘new’ areas and on heavy soils. Sandhill soils can also be prone to development of wheel ruts. It is essential this issue is addressed before bogging and ruts become significant. If ruts are allowed to develop, then major problems with machine operation and breakdown are likely. Large stresses are placed on the machine structure if wheels are trying to climb in and out of bog holes in wheel ruts.

When these machines are operating, each tower can carry up to 3 tonnes of weight. To minimise the occurrence of wheel tracking, the following management solutions are suggested:

- Wherever possible, ensure wheels travel over firm and dry ground;
- Ensure correct tyre selection and maintain correct tyre pressures;
- Use ‘boombocks’ and/or half circle sprays upon wheel towers; these direct irrigation water behind the machine and away from tyres; and
- Apply low irrigation rates for the initial irrigation events after soil cultivation.
Some irrigators build dedicated tower tracks to avoid wheel tracking programs. Extreme care must be exercised if considering this, as raised tracks can result in towers ‘sliding off’ which can result in significant stress being placed on the main structure, resulting in structure failure and towers collapsing.

With towable machines, it is essential the machine is correctly aligned after each move to ensure the machines follows existing tracks. Tow tracks should be considered when moving between circles and should be formed carefully with minimal camber to minimise problems when moving between sites. Tow patterns and tracks should be planned when designing the system to minimise towing over wet and rough soils.

Figure 14. The development of wheel ruts can result in machine failure (Source: Smith, P.).

7.4. Monitoring Centre Pivot – Linear Move performance

It is essential the performance of any CP/LM is checked regularly. This is apart from the normal maintenance schedule which should be supplied when the machine is purchased.

There are a number of measures of CP/LM performance. The three key measures are application rate, uniformity and application efficiency (refer to Section 6.1) and it is
important that users are aware of how these impact upon machine (and ultimately crop) performance.

It is important to know the average and instantaneous application rates in order to match the machine to the soil type(s) and to manage the irrigation interval (schedule) correctly.

In order to measure the performance of CP/LM systems, there are in-field tests which can be done relatively easily and cheaply. These include measuring sprinkler coverage (using catchcans), measuring flows (using containers of a known volume) and measuring pressures (using pressure gauges). Specific information and assistance on measuring in field performance can be supplied by your local I & I NSW Irrigation Officer, or by reference to the CRC IF publication *Improving Irrigation with pivots and laterals* (CRC IF, 2007), which is available as hard copy only.

Table 5 provides a simple checklist guide for irrigators using CP/LM systems. It is not intended to cover every possible situation, but rather to act as a guide for users. In addition to those outlined, daily checks that should be carried include oil (at the pump, motor, and/or gen set, and the drivelines, couplings and gearboxes), fuel, water leaks (at the span joints, goosenecks and drop hoses), bolt tightness and other operational issues. Ensure lightning protection and earthing systems are in place and that machine guidance (on linear moves) arms or cables (and machine barrier stops) are installed correctly.

Because of the nature of these irrigation systems (i.e. small but frequent applications to replace crop water use), it is critical that breakdowns are minimised. Preventative maintenance is critical and suppliers of machines should provide a maintenance schedule which should be adopted.

Importantly, do physical and visual checks of the area or crop being irrigated. Check and document any signs of waterlogging, wheel ruts, poor crop germination, establishment and/or yield. If any problems eventuate, investigate the reasons why, implement strategies to minimise or improve them, and keep on checking. If you don’t monitor and check what your system is doing and how it is performing, you cannot expect to improve and maximise the benefits these systems can provide.
### Table 5. Checklist guide for users of CP/LM machines (adapted from Daley, P. *pers. comm.*).

<table>
<thead>
<tr>
<th>Action</th>
<th>When</th>
<th>Why</th>
<th>How</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure pump flow rate</td>
<td>Start and end of season</td>
<td>To ensure adequate supply</td>
<td>Pump flow meter</td>
</tr>
<tr>
<td>Check machine operating speed and calibration of controls</td>
<td>Start and end of season</td>
<td>To ensure adequate water is applied to the field</td>
<td>Measure distance travelled and time taken</td>
</tr>
<tr>
<td>Check machine operating pressure – at the pump inlet, in the middle and at last sprinkler as a minimum</td>
<td>Monthly</td>
<td>To ensure operating within design parameters and minimise O &amp; M costs</td>
<td>Pressure gauges</td>
</tr>
<tr>
<td>Check individual emitters and check ground clearance of all sprays</td>
<td>Twice monthly (depending on water quality)</td>
<td>To ensure no blockages. To ensure as per design, and to ensure appropriate wetted area coverage.</td>
<td>Measure flow and time taken</td>
</tr>
<tr>
<td>Check flowrates from emitters (minimum of one from each span) and the pressure downstream of pressure regulators</td>
<td>Twice monthly (depending on water quality)</td>
<td>To ensure appropriate flow rates and operating pressures</td>
<td>Measure flow and time taken. Pressure gauges.</td>
</tr>
<tr>
<td>Complete catch can test</td>
<td>Once per season</td>
<td>To ensure machine performance and check distribution uniformity</td>
<td>Use catchcans and measuring cylinders</td>
</tr>
<tr>
<td>Check machine tyre pressures on each tower</td>
<td>Monthly</td>
<td>Minimise soil compaction, wheel tracking, bogging etc</td>
<td>Pressure gauge</td>
</tr>
<tr>
<td>Check water quality</td>
<td>Start and end of season</td>
<td>To identify any changes in water quality, which may impact on plants and machine performance</td>
<td>Obtain representative sample and send to accredited laboratory</td>
</tr>
<tr>
<td>Check filters and trash screens</td>
<td>Weekly (depending on water quality)</td>
<td>To ensure suction lines not blocked</td>
<td>Observation</td>
</tr>
<tr>
<td>Review crop and machine performance at end of crop production</td>
<td>End of season</td>
<td>To determine limitations/problems and to rectify/improve performance</td>
<td>Check total crop wateruse, crop yield etc</td>
</tr>
<tr>
<td>Check soil immediately after irrigation to identify soil infiltration problems</td>
<td>After each irrigation</td>
<td>To determine if soil and machine characteristics are matched, and to determine what remedial action(s) are necessary</td>
<td>Observation, soil probe, drainage lines</td>
</tr>
<tr>
<td>Drain water from pipe lines</td>
<td>After each irrigation</td>
<td>To ensure pipe lines remain dry between irrigation events to minimise corrosion.</td>
<td>Install drain plugs</td>
</tr>
<tr>
<td>Flush pipe lines</td>
<td>Monthly (depending on water quality)</td>
<td>If using fertigation, and/or surface or groundwater to flush chemicals and sand/dirt particles which can settle in pipes.</td>
<td>Install large valves at end of pipeline and flush with high volumes.</td>
</tr>
<tr>
<td>Check machine alignment, control boxes, and automatic shutdown</td>
<td>Monthly</td>
<td>To ensure correct machine operation, ensure machine integrity and safe operation</td>
<td>Follow operating procedures</td>
</tr>
</tbody>
</table>
8. References


Australian and New Zealand Environment Conservation Council (2000). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality. ANZECC, Canberra, ACT.


Cooperative Research Centre for Irrigation Futures (2007). National Training Course Improving irrigation with pivots and laterals. IF Technologies Pty Ltd, Queensland.


Daley, P. Daley’s Water Service Pty Ltd, Clifton.


Fowler, J. District Agronomist. NSW DPI, Deniliquin.

Hughes, J.D. (1999). Southern Irrigation SOILpak. NSW Agriculture, Orange, NSW.


York, S. Product Manager, Pivot and Hard Hose Systems. Water Dynamics, Yarrawonga.
Appendix A: Matching average application rates to soil infiltration rates

Average Application Rate (AAR) is determined by the emitter flow rate, the speed of the machine and the throw of the sprinkler. If the AAR is greater than the soils’ infiltration rate, then water will pond on the soil surface. This will result in localised run-off when surface storage capacity is exceeded and will lead to under or over-watering in different areas of the crop, movement of nutrients and chemicals and uneven/poor crop performance leading to reduced application uniformity and application efficiency.

AAR is a greater issue on centre pivot machines than it is on lateral move systems. As the distance of a sprinkler from the centre of the circle increases, so does the distance the sprinkler has to travel around the circle and hence so does the ground speed and the application rate (Table A1).

Table A1. AAR of the outside sprinkler on various sized centre pivot irrigators with an application rate of 12.5 mm/day (Source: Barron, 2005).

<table>
<thead>
<tr>
<th>Length (or radius) of centre pivot (m)</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approx. Area (ha)</td>
<td>13</td>
<td>28</td>
<td>50</td>
<td>79</td>
<td>113</td>
</tr>
<tr>
<td>Distance around outside of pivot (m)</td>
<td>1,257</td>
<td>1,885</td>
<td>2,513</td>
<td>3,142</td>
<td>3,770</td>
</tr>
<tr>
<td>Speed of outermost tower (m/hr)</td>
<td>52</td>
<td>79</td>
<td>105</td>
<td>131</td>
<td>157</td>
</tr>
<tr>
<td>Time to cover 10 m (minutes)</td>
<td>11.5</td>
<td>7.6</td>
<td>5.7</td>
<td>4.6</td>
<td>3.8</td>
</tr>
<tr>
<td>AAR (mm/hr) using a sprinkler with 10 m diameter of throw</td>
<td>65</td>
<td>99</td>
<td>131</td>
<td>164</td>
<td>196</td>
</tr>
</tbody>
</table>

It is essential that AAR is considered during the design stage and that every effort is made to ensure that the AAR does not exceed the soil infiltration rate.

There are a range of factors which control soil infiltration rates. These include:

- Soil type, particularly texture (i.e. clay content) and structure;
- The water holding capacity of the soil profile and the moisture content prior to irrigating (i.e. the antecedent moisture content);
- Sodicity, which affects dispersion and blocking of soil pores;
• Organic matter content, which affects soil slaking and crusting, particularly in soils with a high silt and fine sand content (i.e. red brown earth and transitional red brown earth soils); and

• Bulk density and compaction from stock and machinery.

Even at the same location, soil infiltration rates will change with time, as:

• They are generally higher for autumn pre-irrigations (when the soil is drier) than for spring irrigations;

• They generally decline as the irrigation season progresses, mainly due to dispersion of fine soil particles which block soil pores; and

• They are affected by cultivation practices and crop/pasture type.

A number of key points can be made regarding AAR and soil infiltration rates by examining Figure A1:

• For three of the major soil types found in the Riverina, infiltration in the first minute of an irrigation (or rainfall) event is extremely high, with water entering the soil through large cracks. Once these cracks are filled, infiltration rates rapidly decrease.

• In red brown earth (RBE) soils with sodic B horizons and non self mulching clays (NSMC), final infiltration rates become extremely low.

• Comparing the two graphs in Figure A1, it can also be seen that a high soil water holding capacity (or a drier soil) allows more water to enter the soil in the initial crack fill phase.

• An application of 12.5 mm of water applied by a 600 m long centre pivot (i.e. application time of 3.8 minutes on the outer sprinklers) would not result in any runoff, even for the RBE with low water holding capacity (or high antecedent (or starting) moisture content). It might, therefore, be presumed from this data that both the sodic RBE and NSMC can be successfully irrigated using CP/LM systems.

Whilst this might be true for the first irrigation of a season, the problem with these soils arises with subsequent irrigations. CP/LM systems commonly installed in the southern Riverina apply 12.5 to 15 mm/day. If sodic RBE and NSMC soils were irrigated at a soil moisture deficit of only 12.5 to 15 mm, they would not be dry enough to have cracked
sufficiently to allow rapid entry of water. Furthermore, irrigation of these soils at such a short irrigation interval would leave them continually wet and likely lead to significant waterlogging losses.

If the irrigation schedule was pushed out to 50 to 60 mm in order to improve soil aeration and induce soil cracking, then it may not be possible for the CP/LM system to “catch up” or to apply this depth of water in time to avoid drought stress. Furthermore, soil cracks are likely to close after the first couple of irrigation passes and the reduction in infiltration rates will lead to run-off in subsequent irrigation passes. This, coupled with the very low internal drainage rates of these soils, will prevent re-wetting of the deeper profile without a sufficient driving head (or soil wetting).

None of these problems exist for the other major soil types found in the southern Riverina.

Figure A1. Cumulative infiltration
The above graphs analyse the cumulative infiltration in six soils that are representative of three major soil types found in the Riverina, with (a) high and (b) low initial soil profile water contents (adapted from Austin & Prendergast, 1997 and Maheshwari & Jayawardane, 1992). The dashed horizontal line shows an application depth of 12.5 mm and the dotted vertical lines show application times corresponding to the centre pivot lengths in Table A1.
In general, infiltration rates decrease across the range of soil types found in the southern Riverina in the following order:

\[
SS > RBE > \text{non-sodic } RBE = SMC > NSMC > \text{sodic TRBE}
\]

where:

- SS = Sandhill soils
- RBE = Red Brown Earth soils
- SMC = Self Mulching Clay soils
- NSMC = Non Self Mulching Clay soils
- TRBE = Transitional Red Brown Earth soils

As a rule of thumb, infiltration rates on sandhill soils and RBE’s will be high enough to pose no limitation to centre pivot machines that are less than 400 m long. Care should be taken if considering a centre pivot longer than 400 m and soil infiltration rates should be assessed before proceeding, particularly if the site has significant slope.

On non-sodic TRBE and SMC soils, centre pivots should be kept less than 300 m and end guns should not be used because of their high instantaneous application rates and droplet energy.

Sodic TRBE and NSMC soils are generally considered unsuited to sprinkler irrigation because of their poor internal drainage which makes wetting them to depth difficult. Furthermore, their propensity to become waterlogged makes the large capital investment in CP/LM financially risky. Better returns to capital will generally be achieved on these soil types if they are used to produce surface irrigated crops (e.g. rice). If overhead irrigation of these types of soil is being considered, then linear move systems are preferred. More intensive soil and irrigation management (e.g. soil moisture monitoring) will be needed and soil tests conducted to assess gypsum requirements.

There are a number of ways to reduce AAR on CP/LM machines in order to match application rates to soil infiltration rates. These include:

1. Increasing the wetted footprint, which can include increasing the throw distance of emitters and installation of spreader bars (where two rows of lower flow sprinklers are placed parallel to each-other, but on either side of the main pipeline).
2. Ensuring the centre pivot is not too large (in length) so that excessively high application rates are not applied (or install a linear move instead).

In addition, there are a number of management practices that can/should be adopted to preserve and potentially improve soil structure and, hence, soil infiltration rates:

1. Retaining stubbles will reduce drop impact and surface sealing and can increase surface water storage and reduce runoff.

2. Minimising tillage and adoption of direct drilling techniques will build soil organic matter levels and help to maintain large soil pores and cracks.

3. Control traffic and stock movements to reduce soil compaction.

A rough soil surface (e.g. ridges behind sowing or cultivation equipment) will also increase surface storage, trap water and increase the opportunity time for water infiltration. However, this should be balanced against the need for winter drainage.