Repair or replace?

Line-shaft vs submersible pumps

October 2019 | J Welsh and J Powell

Repair or replace? Line-shaft vs submersible pumps

JM Welsh & JW Powell

Abstract

As traditional line-shaft pumps reach the end of their life, what are the options for irrigators? While line-shaft pumps may be more efficient per unit of energy, there are advantages of changing to submersible pumps. This report reviews the repair and replacement options as well as important considerations for monitoring and maintaining pump performance to ensure least-cost per megalitre extraction.

Acknowledgement

Disclaimer

Citation

Executive Summary

With access to surface water currently at historic lows, most broad-acre irrigation industries are heavily reliant on groundwater reserves to continue production. Irrigators are increasingly finding that bore pumps installed in the 1970-80s are worn out, inefficient or oversized. Adoption of new technologies has enabled increases in water, energy and labour productivity over time. Australian irrigated cotton farms have been able to respond to fluctuating prices through input substitution (capital for labour) and adapting technologies to improve operating margins.

This study investigates and compares two groundwater pumping alternatives: line-shaft pumps and submersible pumps. Each has a different resource and capital requirements. Inefficient line-shaft pumps can be easily remedied with an overhaul of new shaft and pumping equipment, but reliance on heavy industrial machinery has timeliness, convenience and cost implications for irrigators. Submersible pumps have higher capital and variable cost (per megalitre) than line shaft pumps due to energy losses, although pump and motor can be pulled with minimal machinery and labour input, lowering production risk in the critical irrigation season.

On-site electricity via a diesel genset provides options for submersible pumps to supplement diesel fuel with renewable sources in off-grid locations which can simultaneously lower energy costs and improve sustainability.

The benefits of integrated telemetry for remote monitoring of aquifers and pump performance thereby reducing operating labour are also identified and outlined.

The study also found regular borehole maintenance and cleaning screens can also offer immediate cost savings through higher flows and lower energy costs.

Results show that maintenance, repair and replacement options that save energy and time, will effectively reduce the cost of pumping.

Contents

1. Is it time to repair or replace my pump?

We know that it costs less to move each megalitre (ML) with an efficient pump. How do you know if your pump is efficient?

Simple calculations can be used to understand if your pump is running the way it should be. Industry publications such as 'Improving Energy Efficiency on Irrigated Australian Cotton Farms' and WATERpak outline a method to measure your pump efficiency.

Figure 1 indicates the $/ML pumping costs for a range of irrigation bores in the cotton industry. The blue line indicates the expected pumping costs for an efficient diesel motor and pump and the yellow line indicates the costs for an identical pumping system with an electric motor.

Where the tested sites are close to the line of the corresponding colour, the site could be assumed to be energy efficient. To the contrary, the further the distance away from the corresponding colour line shows a high and energy inefficient pump site.
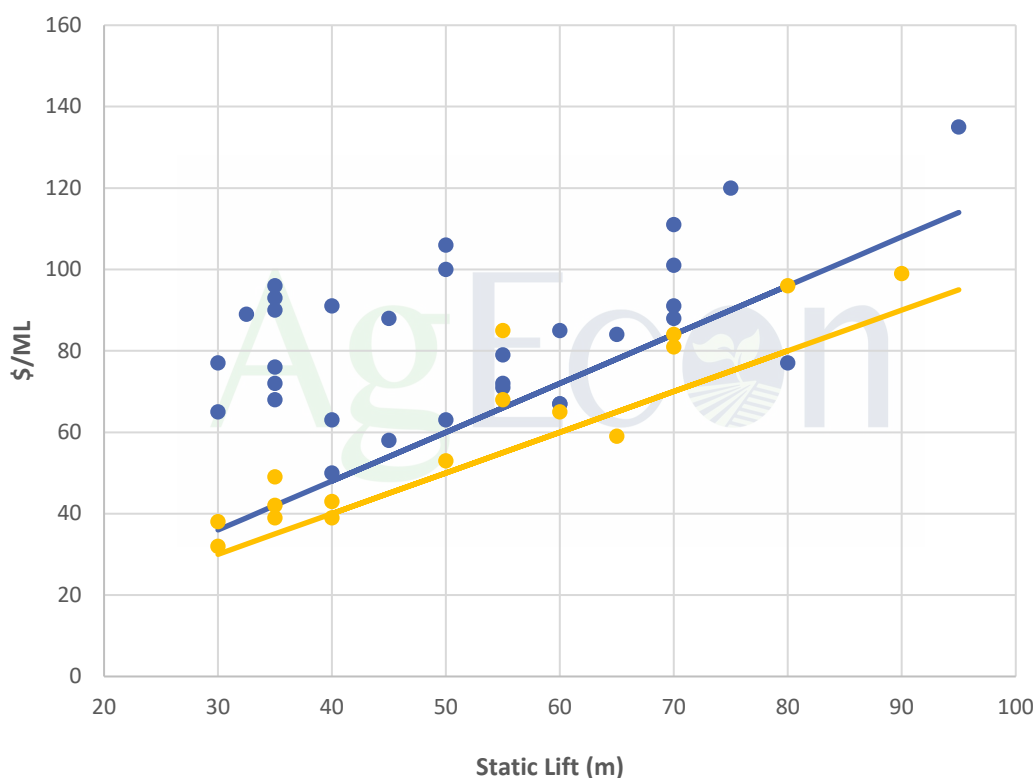

Figure 1: Pumping costs per ML for diesel (blue) and electric (orange) irrigation bores (Source: AgEcon, 2019)

2. An overview of line-shafts and submersibles

2. An overview of line-shafts and submersibles

The pumps traditionally installed for irrigation bores in the Australian cotton industry are vertical turbine pumps (VTP). In this report, we consider traditional VTP that have a very long, thin line-shaft to connect the above-ground motor to the below-ground pump assembly and compare them to a submersible motor-driven VTP, that in contrast has the motor located below and directly connected to the pump assembly down in the bore or well. The comparison is often shortened to *line-shaft* and *submersible*. A diagram of a line-shaft and submersible is shown in Figure 3. Other differences and considerations between these two types of pumps are outlined throughout this report.

Line-shafts

Line-shaft VTP's can be more versatile than a submersible when it comes to motors. A line-shaft may be driven by a vertical motor, an engine through a right-angle gear drive, a horizontal motor through a right-angle gear drive, a flat belt pulley or a v-belt pulley connected to an engine.

Right-angle gear drives commonly range between 95 % and 99 % efficiency, that is, some power is lost through the friction of the gear teeth. Hence, if using an electric motor, where possible it should be mounted vertically and attached directly to the line-shaft, avoiding the need for a right-angle drive.

The actual line-shaft may be enclosed in a tube and lubricated with oil or may be open and lubricated with water. The line-shaft is supported by bearings commonly placed 1.5 m apart for enclosed shafts and 3 m for open shafts. The line-shaft diameter is determined by the power to be transmitted to the pump, the rotational speed, the length of the column and the total pumping head.

The nature of this arrangement means balancing, shaft straightness and motor-shaft alignment tolerances are less stringent than for other pumping arrangements. This results in more structural and shaft vibration problems and a shorter service life. Shallow depth line-shaft pumps tend to be more susceptible to vibration issues than deeper line-shaft pumps.

There is also extra power used due to the line-shaft bearing friction, which can be around 5 m head loss per 100 m of length. This may translate to an extra 2 to 5 kW per ML per 100 metres of depth.

Diesel driven line-shaft VTP's are associated with flexibility in set up, however there are a number of other considerations when comparing diesel and electric motors. **See *Spotlight Autumn 2018 pg 33 - 35***

Submersibles

A submersible motor-driven VTP has the motor located below and directly connected to the pump assembly down in the bore or well. This eliminates the line-shaft, line-shaft bearings, and motor pedestal components – and the associated vibration and wear problems.

A common practice is to eliminate the metal pump column (also called discharge pipe or rising main) completely and to install the submersible with high strength flexible rising main ('lay-flat'). This has multiple benefits such as:

• Allows for installation, pulling up and lowering to be done without a crane using a simple rolling wheel and manitou or front-end-loader;

- Resistance to corrosion, microbiological growth and internal scaling;
- The collapsible design means lifting pumps from deep bores is easier;
- Reduced friction loss – this piping expands a little under pressure which automatically reduces friction loss. The slight expansion and contraction also limit the build-up of scale or encrustation on the inside surface;
- Compensates for misalignment or crooked bores; and
- Including installation, often slightly cheaper over time than metal rising mains.

In some cases, the lay-flat hose may be at risk of tearing, this can be avoided using a PVC lining sleeve within the bore casing. Figure 2 shows the installation of a submersible pump using a roller placed adjacent to the bore hole and gently lowered to the correct height.

Not having the line-shaft and bearings means submersible motor VTPs can operate at higher speeds. This reduces the number of pump bowl stages required and/or allows a smaller diameter well casing to be used. Consequently, the installation cost component is usually lower.

Submersible motor VTPs are compact, easy to handle and do not need a pump house to protect an above-ground motor from the weather. Submersible motors do, however, require power cables which could be damaged, for example against a ragged edge in the bore casing, and they incur a power loss proportional to their length. Additionally, cables are not cheap, so their cost outweighs those of a line-shaft. A cost comparison of each line item is outlined in Table 4 and Figure 8.

Overall, submersibles have a slightly higher capital cost than a line shaft.

Figure 2: Installing a submersible pump with a flexible lay-flat hose using a roller (image courtesy Sapphire Irrigation)

Submersible motors

The three types of submersible VTP electric motors include:

- canned – hermetically sealed to prevent the entry of any liquid. Usually only for small pumps.
- water filled – water is both the lubricant and the cooling medium. These motors use a special water mix and are sealed.
- oil filled – oil is both the lubricant and the cooling medium. These motors are sealed and use oils that are acceptable for potable water.

Canned type motors are slightly more expensive than oil filled, or water filled motors. Oil filled motors in the smaller sizes are less expensive than water filled motors. Canned and water filled motors tend to be more reliable than the oil filled motors because of the complexity of ensuring that the oil can expand and contract without escaping from the motor. Most large capacity submersible pumps sold are water filled.

Submersible motors are less efficient than above-ground motors because of the smaller (non-optimum) diameter designed to fit into bore holes. The difference is in the order of 4 to 6 percentage points less efficient than above-ground motors. This efficiency penalty for a submersible motor is offset for deeper pumps by not having the efficiency losses from the line-shaft bearing friction for a surface mounted motor.

Submersible electric motors usually have a power factor that is 5 to 6 per cent below a corresponding standard electric motor. This is effectively a decrease of performance which needs to be accounted for either by selecting a motor with a slightly higher power rating or including Power Factor Correction (PFC) in the installation.

Submersible motors also tend to be more susceptible to failure due to overload conditions, low voltage conditions and voltage surges in the power supply. This is due to the mechanical limitations of the non-optimum design. It is therefore necessary to select more comprehensive motor control and overload equipment for a submersible application and to be very diligent in monitoring the motor.

> **If a submersible is set correctly and carefully monitored it will have fewer maintenance requirements than a line shaft.**

Placement

Care must be taken to ensure that a submersible pump is not placed too close to the bottom of the bore and that the clearance between bore casing and the pump is neither too small nor too large. The submersible motor depends on the flow of water past the motor for cooling and if the flow is inadequate or if sand builds up around the motor, the heat cannot be dissipated, and the motor is likely to fail. Water flow velocity must be between 0.15 m/sec and 3.0 m/sec (Engineering, 2019). If the flow is less than 0.15 m/s the motor is likely to overheat and burn out. If the flow is more than 3.0 m/s, motors will also overheat because the high velocity does not allow efficient transfer of heat from the motor to the water.

With submersible pumps, check valves should be installed to hold pressure in the system when the pump stops. The values prevent backspin, water hammer and upthrust, all of which can reduce service life and risk immediate failure of the pump or motor. Swing type check valves should never be used, however, because when the pump stops there is a sudden reversal of flow before they close, causing a sudden change in the velocity of the water. Spring loaded check valves close quickly as the water flow stops and before it begins to move in reverse, these are the recommended value.

Power supply and cable size

Voltage drop in the cable should be low. The longer the cable and the smaller its cross-sectional area, the larger the losses will be and the lower the voltage that arrives at the motor terminals.

Cable capacity should be matched to the expected motor amperage, which is the full-load current specified for that motor, even though this current may only be reached a small proportion of the time. The voltage drop through the cable should not exceed 3 % and the voltage at the motor terminals must never be lower than the minimum voltage for the motor (which is the rated voltage minus 10 %).

Power supply from the grid is expected to be consistent but variations can occur. Permitted variation is ±6 %. Sometimes the variation is greater than this and occurs frequently. Voltage losses in the cabling are additional to this.

If the voltage drops, electric motor torque and loaded speed will be reduced. This results in reduced motor efficiency, increased power consumption and increased generation of heat in the motor. If a fully loaded centrifugal pump motor receives 10 % under-voltage, power consumption increases by approximately 5 % and motor temperature by about 20 %. If this temperature is too high for the insulation material around the windings, this material can short-circuit, and the stator will be destroyed. It is therefore important to monitor the incoming power supply.

If an electric motor is powered from a generator-set rather than mains power, it is possible that the supply frequency will be different from the motor design frequency (50 Hz in Australia). Increased frequency will increase pump speed and will almost certainly raise the duty point of the pump, potentially causing the motor to become overloaded.

Submersible motor cables are different to other cables. They must:

- be suitable for the wet, enclosed environment (PVC sheathed cables are not submersible rated and should not be used)
- be sized to deliver adequate voltage to the motor
- work without overheating or burnout – both in water and air
- satisfy any local safety and/or drinking water requirements
- mechanically withstand installation conditions

To preserve the life of the motor, cable size should be carefully sized to motor requirements.
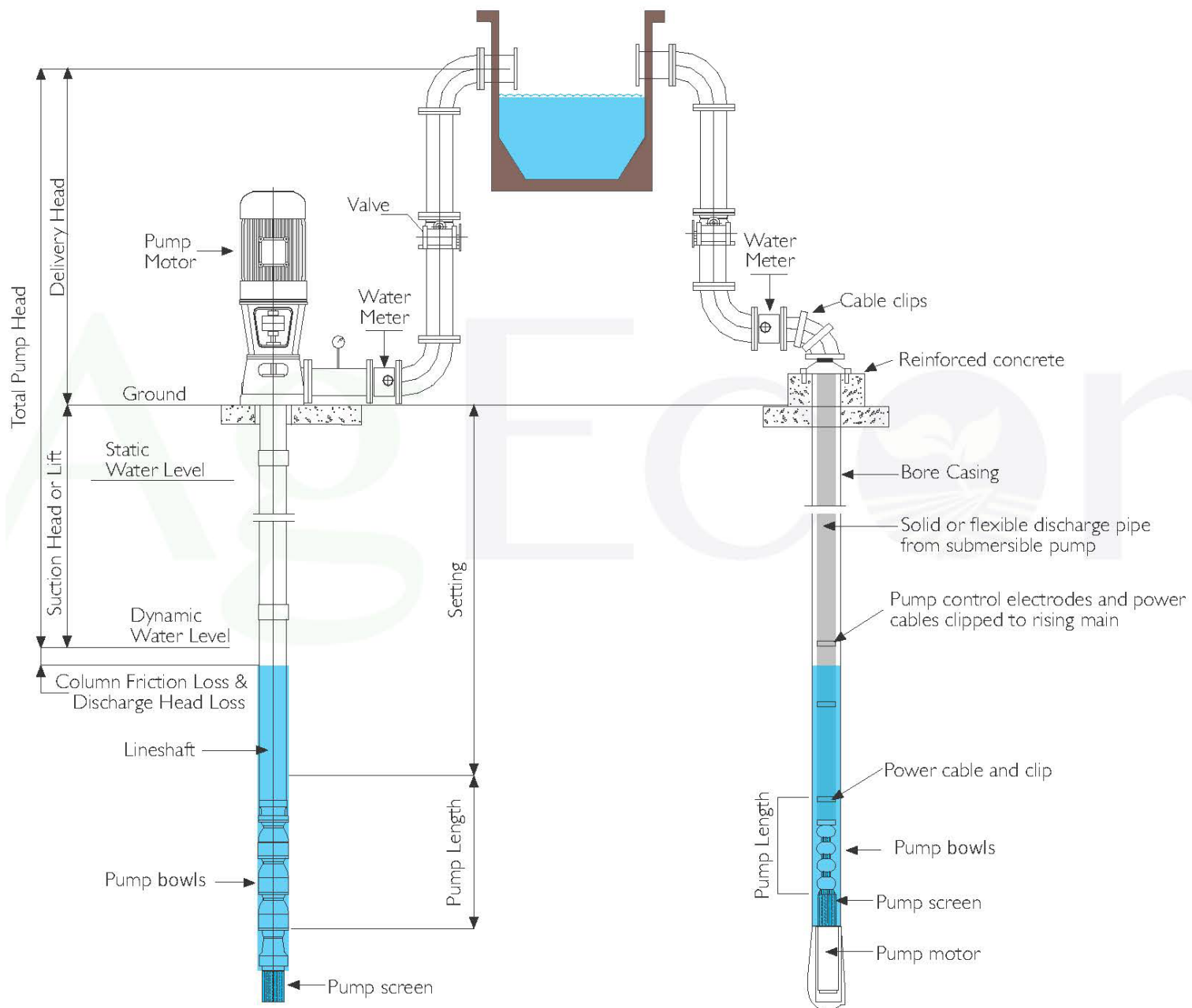
Figure 3: Illustration of a line-shaft pump (LHS) verse a submersible pump (RHS)

Wear and tear limits starting submersibles

Submersible motors should only be started a certain number of times per day, as consistently exceeding the recommended number shortens the motor life. If, for example, a pump is starting/stopping on auto due to low water levels, it might exceed the recommended number of starts and the motor will be damaged. Table 1 provides an indication of the maximum number of times motors should be started before damage occurs.

Table 1: Wear and tear limits of the number of starts for submersibles (Grundfos Pumps, 2019a)

Motor Diameter	Min. starts per year	Max starts per hour	Max starts per day	Max water temp
100mm	1	100	300	40°C
150mm	1	15-30	300	60°C
200mm	1	10	240	60°C
250mm	1	8	190	60°C
300mm	1	5	120	60°C

Rapid cycling causes the motor to overheat, as it does not get enough time to cool down from the previous start/run. When a motor is started, it draws 4 to 6 times the normal full load current which creates high temperatures in the stator and rotor windings. Several starts in quick succession will almost certainly cause the motor to overheat, eventually resulting in failure. Additionally, the thrust-load bearings in water-filled motors need water pressure to provide effective lubrication. Rapid cycling does not allow enough pressure to build, which may result in bearing failure.

Manufacturers recommend that motors be allowed to cool for a minimum of 15 minutes before being restarted and to run for at least 1 minute after start-up to allow the heat generated during the starting cycle to partially dissipate (Submersible Motor Engineering, 2015). Many pumps have inbuilt protection that will avoid stop-start issues related to intermittent electrical supply (volts and amps).

Soft starters and variable speed drives

Care must be taken when using soft starters or variable speed drives on all pump motors. For submersible motors, maximum run-up time must not exceed four seconds, but many soft starters and variable speed drives take longer, often around ten seconds. The longer period is fine for normal, air-cooled electric motors but is too long for submersible motors and will result in overheating of bearings and electricals.

For variable speed drives, the electronic filtering needs to be of higher quality for submersible motors than for air-cooled motors because the acceptable variations in voltage, frequency and amperage are much lower.

Submersible motors should only be started a certain number of times per day, as consistently exceeding the recommended number shortens the motor life. Several starts in quick succession will almost certainly cause the motor to overheat, eventually resulting in failure.

Cathodic protection of submersibles

Cathodic protection is a technique to control the corrosion of a given metal surface by purposely making this surface into the cathode of an electrochemical cell. It is a means of managing corrosive water.

There are two methods:

- Galvanic – using a sacrificial metal
- Impressed Current – using a DC power supply and an inert anode

Using sacrificial anodes has an environmental impact that should be considered. i.e. salts are formed as a by-product which may have an adverse effect on crop growth or soil structure. This method requires monitoring in order to find the correct time for replacing the sacrificial anodes. An advantage is that the need for protection is apparent from the rate of deterioration of the sacrificial anode. Some individual testing estimates Zinc anodes have a life of one to four years, depending on temperature, flow and chloride content (Grundfos Pumps, 2019b).

The 'impressed current' method requires knowledge of the actual potential between the metal that needs protection and a reference electrode. It therefore requires individual design. The DC supply needed is usually 50 volts with 10–100 amps. An advantage of this method is that it is inert, meaning that it does not release any chemical agents to the environment.

**Cathodic management extends the life of the
submersible motor**

Figure 4: Galvanic cathodes can be attached to the bottom of the pump to manage corrosive water (Photo courtesy Gill Photography).

Matching motor to pump

Matching the drive motor to a pump is important for both submersibles and line-shafts. This is to avoid having an undersized motor that will struggle to deliver and burn out or having an oversized motor that costs more to buy and may run inefficiently at less than full load. Under-sizing is usually more of an issue for electric motors and over-sizing for internal combustion engines.

Engines and electric motors should be matched to the power required by the pump. Where the pump duty varies a lot, for example operating several centre pivots sometimes separately and sometimes at the same time, the power range required will be fairly high and might necessitate installing an engine/motor than can deliver maximum power when required but will then be operating inefficiently at lower power requirements.

However, for bore applications in surface irrigation systems, the pump duty is consistent, so an engine/motor that closely matches the power required, with an appropriate safety factor, is all that is needed. As a guide, the safety margin for electric motors is commonly 10%. i.e. the continuous power rating should be 110 % of the maximum power required, and for internal combustion engines, the safety margin is 30 %. i.e. the continuous power rating should be 130 % of the maximum power required.

Online calculators may be useful. An example submersible pump calculator can be found here and genset sizing calculator for pump motor can be found here. Remember, correct sizing will impact energy efficiency.

> **Considering purchase price, maintenance and traditional energy sources, energy usage is the largest cost over the life of a pump.**

Technical comparison of Line-shaft and Submersible Pumps

When both bore-pumping methods are examined side-by-side, suitability can be better identified considering the timeliness of crane availability, labour and support services. Table 2 shows the pros/cons of line-shaft and submersible pumping systems.

A cost comparison is found in Section 6, which includes a small survey of commercial pricing for each line-item.

Table 2: Comparison of line-shaft and submersible pumping systems

Line-shaft	Submersible
Pump stage efficiency of 70 to 80%. Lower head per stage and flow per unit diameter.	Pump stage efficiency of 70 to 80%. Generally, higher flow per unit diameter.
Higher motor efficiency	4% to 6% lower motor efficiency – operates in oil at elevated temperature
Normal power factor	Power factor 5% to 6% lower than a standard electric motor
	More susceptible to failure due to overload, low voltage or voltage surges
Long, thin line-shaft connects an above-ground motor to below-ground pump assembly – results in structural and shaft vibration problems. Little loss in power cable (if electric motor rather than diesel)	Long power cable required – could be damaged. Cable at least partially submerged and attached to hot tubing.
Extra power required for line-shaft bearing friction – around 5 m head loss per 100 m of length, extra 2 to 5 kW per 100 metres of depth.	Significant energy loss in long power cables.
Motor, thrust bearing and seal accessible at surface	Motor, thrust bearings, seal, and power cable in well – need to be pulled up
Usually lower speed (1,450 rpm), usually lower wear rate	Usually higher speeds (3,000 rpm), usually higher wear rate
Shallower settings, 600 m maximum	Deeper settings
Longer installation and pump pull time	Quicker installation and pump pull time
Well must be relatively straight or oversized to accommodate stiff pump and column	Can be installed in crooked wells up to 4 degrees deviation per 30 m, up to 75 degrees off vertical. Soft hose may have a risk of tearing, this can be avoided using a PVC lining sleeve inside the bore casing.
Impeller position must be adjusted at initial start-up	Impeller position set
Generally a lower purchase price	Generally a higher purchase price

Line shafts are the more energy efficient option, however the key benefit of a submersible is timeliness of repairs.

3. Hybrid energy options

The first solar-diesel hybrid submersible 55kW pump installed in Australia in 2015, halved pumping costs for the irrigator (image courtesy Jon Welsh).

3. Hybrid energy options

With rapid gains in renewable energy drive technology and cost-competitive renewable energy generation, opportunities exist for groundwater irrigators to blend solar Photo Voltaic (PV) with diesel-powered electricity. Such opportunities are unavailable for traditional diesel-driven line-shaft pumps whereby solar PV cannot blend with energy produced by the diesel flywheel. CRDC supported studies by Powell et al. (2019) found moving from a diesel-powered turbine to a solar-diesel hybrid can halve pumping costs on farms when water can be stored. Similar studies for grid-connected cotton irrigators in Queensland also found supplementation with renewable energy can reduce pumping costs (Welsh and Powell, 2018).

Analysis undertaken of a 55 kW submersible pump comparing solar PV both on-grid and off-grid, found utilisation of energy produced in daylight hours to be the limiting factor of investment viability. When grid connected, access to a feed-in-tariff enables greater financial returns with lower usage when compared with off-grid. Figure 5 shows the changing Return on Investment (ROI) at various utilisation rates for on-grid solar PV pumps (orange bars) and off-grid solar/genset pumps (teal bars). When a pump is driven by solar during daylight hours over the summer growing season only (LHS bars) and connected to the grid the project returns achieve approximately 13 % ROI. Similarly, when an off-grid hybrid pump is utilising solar PV during the summer season complemented with a diesel genset (without access to a feed-in-tariff) returns are much lower (5 % ROI). Not until daylight pumping extends to year-round, can off-grid returns compete with on-grid supplementation of solar PV. The value of project benefits attributed to the feed-in-tariff is illustrated by the difference between the orange and blue bars for each scenario.
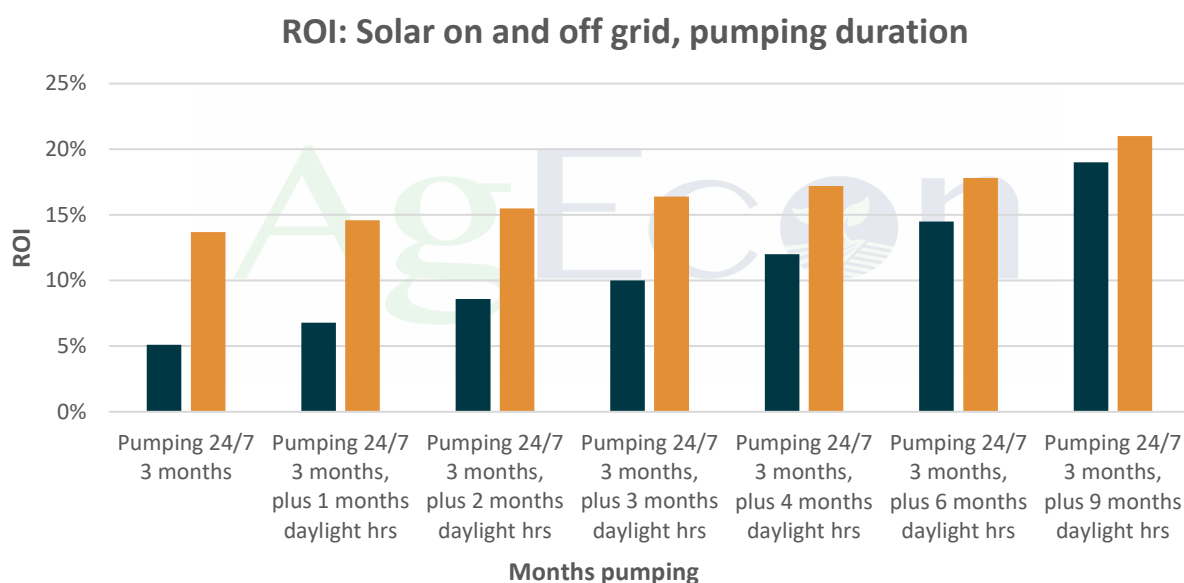
Figure 5: ROI and utilisation rates of solar PV comparing on-grid (orange bars) with off-grid (teal bars) using a 55kW submersible pump. Scenarios (from L-R) show operating full-time for 3 months during the growing season, extending to daylight pumping hours for 4,5,6,7,9 and 12 months of the year.

Opportunities exist for groundwater irrigators to blend solar Photo Voltaic (PV) with diesel-powered electricity. Such opportunities are unavailable for traditional diesel-driven line-shaft pumps whereby solar PV cannot blend with energy produced by the diesel flywheel.

4. Pump maintenance & monitoring

4. Maintenance and monitoring

Maintenance of line-shaft pump motors is easier compared to a submersible because the motor is on the surface and can be checked daily and accessed immediately if required. Although the pump cannot be physically observed and checked, some indicators of performance and of possible problems developing are easier to observe due to the line-shaft e.g. vibration and noise.

Repairs and maintenance of line-shaft pumps can be done by a wide range of service contractors whereas submersible units with solid rising mains nearly always must be serviced by the supplier or their agents. However, if submersibles are installed using flexible rising mains, the job of lifting the submersible is not quite so specialised.

A properly installed submersible pump may run for years with minimal maintenance and it is not necessary to inspect submersible pumps on a daily, semi-annual or even an annual basis. However, because both the pumps and motors cannot be physically inspected daily, maintenance depends very much on good monitoring.

Items to monitor include:

- ✓ electrical meter readings (kWh, Amps, volts) – amperage of the motor, along with motor temperature, are the most important for monitoring the unit. Fluctuating and/or rapidly increasing current consumption indicates mechanical problems in the pump or motor. Strong oscillation of the pressure and at the same time of the amperage can be caused by irregular water inflow.
- ✓ the flow rate of the installation (e.g. ML/day, L/s) – decreased output might be caused by a low water table, reduced bore yield, an obstruction in the screen or pump inlet, restricted or worn impeller, failing motor.
- ✓ motor temperature – overheating might indicate there is insufficient water in the well to keep it cool, the power supply is poor quality, or that the pump or motor is failing.
- ✓ static water levels and drawdown.
- ✓ pressure gauge readings at the surface on the pump discharge.
- ✓ the total volume of water (ML) produced by the bore/well.
- ✓ operating hours.
- ✓ service intervals for valves and seals – ensure they are serviced or replaced in accordance with the manufacturer's directions.
- ✓ specific capacity of the bore/well – this is the yield per unit drawdown expressed as litres per minute (L/m) or megalitres per day (ML/d) per metre of drawdown. It should be monitored annually, and a significant decrease indicates the bore efficiency is decreasing, due to things such as screen fouling, screen failure, bore failure, and so on.

Good record-keeping plays a crucial role in determining when a submersible pump should be pulled for service or replacement. Best practice is to have pressure, flow, standing water level, drawdown and power supply logged over time and stored.

Review your records regularly. An abrupt change, or a significant change that occurs over time, indicates that the pump should be pulled up and examined. The importance of keeping records and documenting maintenance activities cannot be emphasized enough – this will signal when issues are developing, subsequently allowing them to be fixed at an opportune time, such as the off-season or perhaps between irrigation events, rather than at the peak of the irrigation season.

When the water lubricated sleeve bearings in the pump bowl units wear, the pump shaft, which is in compression, loses its support and starts to whip. This reduces the pump life and if the

bowl unit is not repaired soon enough, it may ruin the submersible motor. Unfortunately, it is difficult to determine from the surface that this wear is taking place. Servicing of bearings at the specified intervals is imperative.

Drawdown is a component of the Total Pumping Head – the greater the drawdown, the greater the Total Head. Greater head means higher energy costs, which is an immediate cost. If the drawdown is increasing, it might be an indication that the bore installation is operating inefficiently, which may signal an impending large cost. The screen in the casing could be suffering some blockage, or the bore itself might be degrading from movement of finer particles into the aquifer, reducing the flow rate, or from other impediments such as iron bacteria build up. Increasing drawdown might also be a result of the water table declining through lack of recharge, as occurs in a drought, or because of over-pumping.

The following regular inspections of line-shaft and submersible bore/well pumps should be made:

Frequently:

- ✓ Check for unusual noise, vibration, and bearing temperatures
- ✓ Check the piping for leaks
- ✓ Check the condition of electrical wiring

Three-monthly:

- ✓ Check that the foundation and the hold-down bolts are tight

Annually:

- ✓ Check the pump flow rate
- ✓ Check the pump pressure
- ✓ Check the pump power

When a submersible pump is lifted:

- ✓ Camera inspection of the bore casing and screen
- ✓ Conduct electrical test on the motor (insulation and amperage)
- ✓ Check condition and operation of valves

Repairs and maintenance of line-shaft pumps can be done by a wide range of service contractors whereas submersible units with solid rising mains nearly always must be serviced by the supplier or their agents. However, if they are installed using flexible rising mains, the job of lifting the submersible is not quite so specialised.

5. Bore hole maintenance & monitoring

5. Bore hole maintenance and monitoring

Bore restoration and maintenance

Irrigation bores can become damaged and inefficient over time from biofouling iron bacteria, rusting of casings and screens as well as physical blockages of pumps and boreholes. Restoration techniques include airlifting, jetting, flushing, surging and bore casing re-lining. Whether these need to be done is determined from the monitoring records and in consultation with your pump specialist.

Surging is the repeated injecting and flushing out of water in a bore. With repeated flushing, debris is washed away.

High-pressure jetting uses an adjustable, multi-head, water-powered jet that is lowered into the bore and injects water at high pressure, dislodging debris from the casing and screen.

Hydro-fracturing is another technique where water is sent into the entire bore at high pressure. The water removes debris from clogged openings in the screen and might crack or clear the aquifer formations a little and improve the water flow.

Chemical treatment is necessary on some occasions, often combined with surging and flushing. For example, chlorine or other disinfectants are used to control biofouling such as iron bacteria. The disinfectant water is surged within the bore and then pumped out. Treatment times vary from a few hours to more than 24 hours.

Acid is used to dissolve iron and manganese oxides and carbonate encrustations, and to create an antibacterial effect by heavily lowering pH. Enough volume is added to push the acid solution through the screen and into the filter pack and formation immediately surrounding the bore. It is left in the bore for around 24 hours and then pumped out.

Air pressure: another restorative activity involving blowing out the bore with a compressor. There are some instances where algae may return soon after air has been used to unblock screens.

Other options include renewing the screens, re-casing with PVC, or even deepening the borehole. The last of these is an expensive operation and cannot be undertaken quickly. It should only be considered when the aquifer level has dropped to consistently problematic levels or the bore has completely failed and needs to be abandoned.

A sample irrigation bore maintenance plan;

- CCTV Downhole camera inspection to be undertaken each time the pump is out for maintenance. This should be completed every 5 years;
- Bore maintenance and redevelopment: this should be completed every 5 years at the same time the pump is out for servicing. The extent of works will depend on the findings of the CCTV Inspection;
- Following the bore maintenance and redevelopment the bore should be treated annually (with pump in place) with a bore cleaning product. Providing the annual dosage (~$600-$2500 p.a) is kept up to date the redevelopment intervals can be increased.

Recommendation courtesy: Luke Woods, ACS Equip Gunnedah / Griffith www.acsequip.com

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Bore maintenance and redevelopment allows the bore to operate at full capacity by removing all growth, biofilms, scale etc. that may be blocking the draw area of the bore and redeveloping the surrounding gravel pack. The redevelopment process not only increases yield in most cases but also achieves greater pumping/energy efficiency and generally the efficiency increases over a 12-month period, easily repaying for the redevelopment cost.
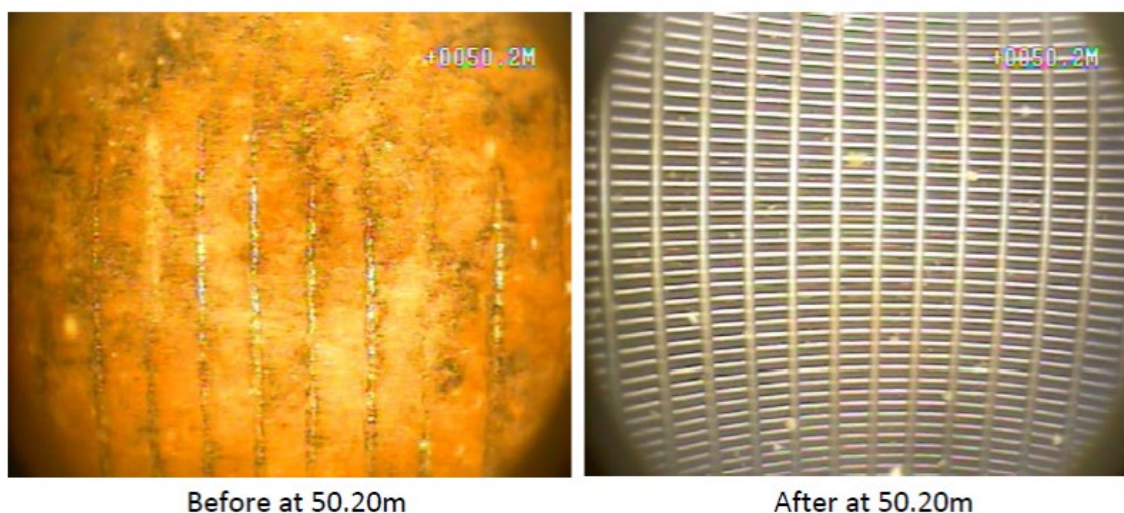

Figure 6: Bore screens, before and after cleaning through targeted chemical jetting (Source: ACS Equip)

Monitoring drawdown and standing water level

To monitor standing water level and drawdown readings, an air-line gauge is the simplest and most reliable method. Electronic means of measurement are available as failure protection devices, but these are not suited for accurate reading of the depth of water.

An airline can be made of copper, plastic or galvanised steel pipe. It should be securely fastened to the column pipe or flexible riser and installed at the same time as the column or flexible riser.

It is necessary to know the exact length of the line. During pump assembly, the lower end of the air line should be attached to the pump approximately 1 metre above the pump suction strainer, and the overall length up to the centre of the discharge flange calculated. The airline is fitted through the discharge head and attached to a pressure gauge. A valve for pressurising the airline is mounted to the discharge head. All joints must be completely airtight and should be sealed with pipe jointing compound.

An air-line gauge is best installed by the contractor at the same time as the pump is installed.

To operate the air-line gauge, pump air into the line via the valve until the maximum pressure is reached. The gauge will return to and hold a pressure reading (P) from where the water level can be calculated using the following formula:

$H = L - (0.102 \times P) - 1$ m

$J = (0.102 \times P) + 1$ m

Where:

P = Pressure Gauge Reading (kPa)

H = distance from the centre of discharge to water level (m)

L = vertical height from top of strainer to centre of discharge (m)

J = height of water above the top of strainer (m)

For example, an air-line tube is 55 m long and its end is 1 m above the pump suction strainer, and the pressure measured for the airline is 205 kPa:

H   = L – (0.102 x P) – 1 m

         = 55 – (0.102 x 205) – 1

         = 33.1 m

The depth to water from the discharge head is 33.1 m.

J   = (0.102 x P) + 1 m

         = (0.102 x 205) + 1

         = 21.9 m

The height of water above the strainer is 21.9 m.

Standing water level readings should be taken when the pump has been stopped for a long enough period to allow the water level to return to normal. Pumping Level or drawdown readings should be taken after the pump has been operating against a normal head for a sufficient period for the water level to remain stationary.

Other methods for measuring water depth include

-   wetted tape – for relatively shallow bores. A gap of sufficient size between the rising main and the bore casing is needed to allow the tape to be lowered.
-   acoustic well sounder – this uses sound waves to measure the depth to water level by bouncing sound waves off the surface of the water.
-   Electric tape – this method uses a battery, insulated wires with exposed ends, and a milli-amp meter or other indicator such as a light. When the exposed ends contact water, it shows on the meter or light. Care is needed to avoid the exposed ends touching metal surfaces and giving a false reading.
-   Integrated wireless communications options – long range UHF and 4G connectors can be fitted as part of pump telemetry configurations for remote monitoring. These provide electronic data at regular intervals and can be powered by batteries charged by PV modules.

Figure 7: Line-shaft pump column in good condition can also be utilised to connect a submersible and lowered to the bottom of an irrigation bore (image courtesy Jon Welsh)

6. Repair or replace?

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Very simply, we can analyse the technical difference and the pumping costs of an electrically driven line-shaft and comparable submersible using an example scenario.

- Bore site: pumping depth 30m, bore diameter 250 mm, pump column 200 mm, flow rate 5 ML/d (58 L/s)
- Column loss: 3.5m/100m = 1.2m
- Discharge head loss: 0.15m
- Total head: 30 + 1.2 + 0.15 = 31.35 m
- ~1 kW extra power for line-shaft mechanical friction

The two example pump options utilised in the comparison are outlined below. The technical summary and comparison of each pumping system is outlined in Table 3.

Everflow line-shaft pump: model 200GHM, 2950 rpm, 12 m H per stage, 73 % efficiency with 3 stages, 9 kW pump power, bowl OD 184 mm.

Goulds submersible pump: model 8FDHO, 2875 rpm, 18 m H per stage, 80.5 % efficiency with 2 stages, 13.5 kW pump power, bowl OD 7.31 inch (185 mm), discharge 6 inch (150 mm).

Table 3: Technical summary of example scenario: line-shaft v submersible (Analysis care of Peter Smith, Sapphire Irrigation, Tamworth)

	Line-shaft: Everflow 200GHM 3-stage	Submersible: Goulds 8FDHO 2-stage
Pump efficiency	73%	80.5%
Water power required	27 kW	27 kW
Column friction loss	1.2 m	1.2 m
6" discharge – head loss	0.15 m	0.15 m
Line-shaft mechanical power loss	1 kW	N/A
Cable power loss	N/A	0.1 kW
Motor power required	~30 kW	~30 kW
Motor efficiency	93%	83%
Power factor	87%	79%
Electric power supply required	37 kW	46 kW
	178 kWh / ML	220 kWh / ML
Variable cost of diesel genset of $0.25/kWh (assuming $1.00/l diesel NET of taxes)	$44.50 / ML	$55 / ML
Cost standard grid off-peak tariff: $0.18/kWh	$32.04 / ML	$39.60 / ML
Cost standard grid peak tariff: $0.35/kWh	$62.30 / ML	$77.00 / ML

A partial budget approach:

In circumstances where the capital costs and ongoing maintenance costs need to be considered, we can use a more complex approach. A partial budget is a method of assessing the likely value of introducing a new activity by comparing it with the existing situation. Put simply, you are comparing the extra costs and returns of the new activity with those of the present activity. The net returns or losses can then be expressed as a percentage return on extra (or marginal) capital, providing a preliminary basis for comparison with other alternatives.

In this instance, two scenarios are compared to an existing inefficient diesel-driven line-shaft pump using the partial budget approach:

- Repair inefficient diesel line-shaft pump
- Replace with a submersible pump and diesel genset

The cost of pumping is derived from Table 3, the labour line item includes farm labour requirements for bore monitoring and maintenance. The addition of telemetry (both scenarios), results in annual labour-savings for monitoring. The overall annual cost is higher for the submersible when compared with the efficient line-shaft operating cost.

Table 4 assumes an existing diesel line-shaft pump is inefficient, operating at 37 % below specifications. Option 1 shows a very high marginal return on capital (31 %) to renew the pump and make repairs to head and column to a high standard. In option 2, a commercially acceptable return can be achieved by changing to a submersible from an existing inefficient line-shaft pump. In this instance, a return on capital of 13 % is generated. Where the existing bore is a grid connected electric line-shaft (as opposed to diesel-driven), the installation of the submersible would not require the genset, lowering the capital cost and increasing the return on marginal capital to 19 %.

Table 4: Partial budget: existing inefficient line-shaft pump vs repair/replace scenario

1. Present pumping activity					
Annual costs Cost of pumping ($/ML) Pumping 500 ML	**Existing** **Inefficient diesel line-shaft** **$61 / ML** $30,500	**Option 1** **REPAIR diesel line-shaft** **$45 / ML** $22,250		**Option 2** **REPLACE with genset/ submersible** **$55 / ML** $27,500	
10yr annualised maintenance costs	$1,500	$900		$700	
Labour component	$3,000	$2,500		$150	
TOTAL	$35,000	$26,650		$28,350	
(a) Expected change in annual costs		$8,350		$6,650	
2. Capital outlay					
Purchases		$47,000	i.	$69,000	ii.
Sales (salvage items)		$16,000	iii.	$16,000	iii.
(b) Expected extra capital		$27,000		$53,000	
3. Return to Marginal Capital					
Return on Marginal Capital =		31%		13%	
$$\frac{\text{Change in annual costs (a)}}{\text{Extra capital (b)}} \times \frac{100}{1}$$		**< 4 year payback**		**< 8 year payback**	

i.   Purchase: $15k engine Repair: $25k head and column, clean screens, $4k telemetry, $3k lift
ii.   Purchase: $18k genset, $39k hose pump, $8k cable and install, $4k telemetry
iii. $8k casing and bearings $8k motor

These scenario's do not value risk. A key benefit of a submersible is the timeliness of repairs and maintenance. Extended break downs in critical crop growth stages can cost tens of thousands of dollars, consideration of these risks may change the submersible as a value proposition.

New pump comparison costing (an indicative guide only)

Item or service	Unit	Line-shaft Example costing[1,2,3,4]	Submersible Example costing[1,2,3,4]
Borehole camera inspection	$/service	$2,500	$2,500
Lifting pump for service/replacement	$/hr or $/service	Crane ($375/hr*8 hrs = $3000)	truck Hiab and wheel ($180/hr*3hrs = $540 *plus travel)*
Borehole maintenance			
- Bundled price: camera inspection, Aquaclear bore cleaner, high pressure liquid flush (60m bore assumption)	$/service	$10,000	$10,000
- Chemical treatment	$/service	$2,500	$2,500
- Camera inspection	$/service	$2,500	$2,500
Spare parts/components			
- Impeller replacement	$/unit	8" $1,400 10" $1,800 12" $2,000	8" $1,400 10" $1,800 12" $2,000
- Bowl replacement	$/unit	8" $1,150 10" $1,900 12" $2,500	8" $1,150 10" $1,900 12" $2,500
- Line-shaft bearings	$/unit or $/m	$250 bronze $50 rubber	$250 bronze $50 rubber
New pump, (assumes 30m bore, 5ML/day)	$/unit	**$49,400 total** $15,000 motor $30,000 pump, column, shaft $4,400 install $4,000 telemetry (optional)	**$65,000 total** $39,000 hose, pump and motor $8,000 cable and install $18,000 Genset (off grid only) $19,000 PVC lining (optional) $4,000 telemetry (optional)
Casing & screen repair/reline	$/service or $/m	$370/m	$370/m

Figure 8: Indicative costings of line-shaft and submersible pumps

1. Andrew Gill, Narromine
2. Sapphire Irrigation, Tamworth
3. Lambert and Torrens, Gunnedah
4. ACS Equipment, Gunnedah

Conclusion

Conclusion

This analysis has compared pumping systems commonly used in the Australian cotton industry for groundwater irrigation: line-shaft turbine pumps and submersible pumps. The traditional line-shaft pumps are characterised by simplicity on one hand, with pump maintenance being a labour-intensive, heavy industrial task on the other. Advances in pump and drive technology has seen submersible pumps becoming increasingly cost competitive for irrigators.

Changing from line-shaft to submersible pumps has its own pros and cons. One of the added bonuses of changing to a submersible is the ability for off-grid systems to seamlessly blend fossil fuel driven engines with renewable sources such as solar. If water storage is available on farm, opportunities exist to significantly lower (or in some cases halve) per megalitre pumping costs for both on and off-grid groundwater irrigators.

Line-shaft pumps use slightly less energy per megalitre per metre head, however, access, high-cost and timeliness of cranes can impact irrigation scheduling and crop yield should breakdowns occur in the growing season.

Lay-flat hose and remote pump and aquifer monitoring technology also offer benefits to irrigators who choose the submersible option, although users should note the number of starts reduces the pump life and increases replacement intervals.

Maintenance and monitoring of either pump configuration is essential and regular calculations of kWh or diesel required to lift 1 ML should be recorded to benchmark energy costs and ensure pump/motor energy efficiency.

The study concluded there are a number of maintenance, repair and replacement options to reduce the cost of pumping by improving energy and labour efficiencies.

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