Irrigation Systems and Energy Efficiency

SURFACE IRRIGATION EFFICIENCY WORKSHOP
UC Kearney Agricultural Center - June 3rd, 2016

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OBJECTIVES

1) Background information on Irrigation Systems in California

2) Review Pumping Efficiency Concepts

3) Considerations about Different Energy Sources

4) Some Sample Calculations
more frequent and flexible delivery schedules are needed by farmers.

WATER DISTRICTS ARE OFTEN NOT CAPABLE TO DELIVER WATER WITH SUCH A FREQUENCY.
Economic Productivity of Water 2000-2010 (DWR, 2013)

680 $/ac-ft => 910 $/ac-ft (34%)

(resulting from more productive crops & more efficient irrigation)
Economic Productivity of Water per crop ($/ac-ft)

- Vineyard: $2,470
- Onion/Garlic: $2,165
- Tomato: $1,652
- Almond/Pistachio: $1,154
- Cotton: $791
- Sugar Beet: $629
- Safflower: $391
- Rice: $374
- Alfalfa: $175
- Corn: $136

Economic Productivity of Water ($ per acre-foot)
HOW ABOUT THE DROUGHT IMPACTS?

California’s farmers in 2014-2015 reacted quickly, by pumping enough ground water to stay competitive.

~ 5% prices increase in 2013-2015
Power and Energy terms

Power (kW, Hp) = Head x Flowrate = H x Q

Energy (kWh) = Head x Volume Water Lifted = Power x Operating Time
Pumping Plant Efficiency

is the overall energy efficiency of the pump and motor considered together

\[
E_{PUMP} = \frac{Power\ Out}{Power\ In} = \frac{Water\ Horsepower\ (WHP)}{Electric\ Horsepower\ (EHP)} = \frac{output\ power\ provided\ to\ water\ by\ the\ pump}{input\ power\ required\ at\ pump\ shaft}
\]

The Water Horsepower (WHP) is given by:

\[
WHP = \frac{TDH\ (ft) \times Q\ (gpm)}{3960}
\]

The Energy Horsepower (EHP) is given by:

\[
EHP = \frac{TDH\ (ft) \times Q\ (gpm)}{3960 \times E_{PUMP}(\%)} = \frac{WHP}{E_{PUMP}(\%)}
\]
<table>
<thead>
<tr>
<th>Common Causes of Poor Pumping Plant Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear (sand)</td>
</tr>
<tr>
<td>Improperly matched pump</td>
</tr>
<tr>
<td>Changed pumping conditions</td>
</tr>
<tr>
<td>* Irrigation system changes</td>
</tr>
<tr>
<td>* Drop in ground water levels</td>
</tr>
<tr>
<td>Clogged impeller</td>
</tr>
<tr>
<td>Poor suction conditions</td>
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<tr>
<td>Throttling the pump</td>
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</table>
Usually the $E_{\text{PUMP}}$ is provided by the pump manufacturer. However, it should be evaluated every several years.

1. A good quality pressure gauge (oil-filled) mounted on the discharge side of the pump
2. Flow meter installed at least 5-8 pipe diameters downstream the pump, (or a 5-gallon bucket + garden hose)
3. A stopwatch and a calculator

**STEP 1 – Find the Total Dynamic Head**

Reading pressure from gauge $\text{psi} \times 2.31$ (a conversion factor) = $\text{feet}$

Add height* if pump is **above** water surface $\text{feet}$

OR

Subtract height* if pump is **below** water surface $\text{feet}$

To get total dynamic head (feet).

*Height is defined as distance from the water surface to the centerline of the discharge pipe.*
STEP 2 – Find the Flow Rate in GPM

If your system has a flow meter, read the gallons per minute (gpm). If the meter reads in cubic feet per second (cfs), multiply cfs times 448.8 to get gpm.

_______ gpm

STEP 3 – Find the Input kW and Energy Horsepower (EHP)

Seconds the disk takes to make 10 revolutions

\[
3.6 \times \text{_______ (revs)} \times \text{_______ (Kh)} \div \text{_______ (secs)} = \text{_______ Input kW}
\]

\[
\text{_______ (KW)} \times 1.34 = \text{_______ EHP}
\]

Seconds the disk takes to make 10 revolutions
STEP 4 – Find the Water Horsepower (WHP)

\[ _____ \text{(TDH)} \times _____ \text{(gpm)} \div 3,960 = _____ \text{WHP} \]

STEP 5 – Determine the Pumping Plant Efficiency

\[ _____ \text{(WHP)} \times 100 \div _____ \text{(EHP)} = _____ \% \text{ Efficiency} \]

Expected Pumping Plant Efficiency

<table>
<thead>
<tr>
<th>Rated Motor Size (HP)</th>
<th>Expected Efficiency (%)</th>
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<tbody>
<tr>
<td>3 to 5</td>
<td>66%</td>
</tr>
<tr>
<td>7.5 to 10</td>
<td>68%</td>
</tr>
<tr>
<td>15 to 30</td>
<td>69%</td>
</tr>
<tr>
<td>40 to 60</td>
<td>72%</td>
</tr>
<tr>
<td>75+</td>
<td>75%</td>
</tr>
</tbody>
</table>

*Note: These efficiencies are for older pumps in excellent condition. New pumps and used pumps under mild conditions or improved design will have higher efficiencies.*
Recommended Corrective Actions

😊 \( E_{\text{pump}} \) greater than 60% - no corrective action

😊 55% to 60% - consider adjusting impeller

😊 50% to 55% - consider adjusting impeller; consider repairing or replacing pump if adjustment has no effect

😊 Less than 50% - consider repairing or replacing pump
### Efficiencies of Standard and Energy-efficient Electric Motors

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>Standard Efficiency</th>
<th>Energy Efficient Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>86.5</td>
<td>91.7</td>
</tr>
<tr>
<td>20</td>
<td>86.5</td>
<td>93.0</td>
</tr>
<tr>
<td>50</td>
<td>90.2</td>
<td>94.5</td>
</tr>
<tr>
<td>75</td>
<td>90.2</td>
<td>95.0</td>
</tr>
<tr>
<td>100</td>
<td>91.7</td>
<td>95.8</td>
</tr>
<tr>
<td>125</td>
<td>91.7</td>
<td>96.2</td>
</tr>
</tbody>
</table>
COMPARISONS BETWEEN DIFFERENT ENERGY SOURCES

<table>
<thead>
<tr>
<th>FUEL SOURCE</th>
<th>PUMP OUTPUT</th>
<th>RELATIVE OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRICITY</td>
<td>0.885 whp-hr/kWh</td>
<td>1</td>
</tr>
<tr>
<td>NATURAL GAS (925 BTU)</td>
<td>61.7 whp-hr/MCF</td>
<td>69.72 times as Electricity</td>
</tr>
<tr>
<td>NATURAL GAS (1000 BTU)</td>
<td>66.7 whp-hr/MCF</td>
<td>75.36 times as Electricity</td>
</tr>
<tr>
<td>DIESEL</td>
<td>12.50 whp-hr/gal</td>
<td>14.2 times as Electricity</td>
</tr>
<tr>
<td>PROPANE</td>
<td>6.89 whp-hr/gal</td>
<td>7.70 times as Electricity</td>
</tr>
</tbody>
</table>

1 MCF of Natural Gas (925 BTU) produces 69.72 times the water horsepower as 1 kW of Electricity.

1 gal of Diesel produces 14.2 times the water horsepower as 1 kWh of Electricity.

Cost of Electricity per Agricultural Use in California (PG&E, 2016)

<table>
<thead>
<tr>
<th></th>
<th>RATE A (&lt; 35 HP)</th>
<th>RATE B (&gt; 35 HP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUMMER</td>
<td>0.278 $/kWh</td>
<td>0.236 $/kWh</td>
</tr>
<tr>
<td>WINTER</td>
<td>0.213 $/kWh</td>
<td>0.182 $/kWh</td>
</tr>
</tbody>
</table>
Assuming an average cost of electricity of $0.227 per kWh, we could afford to pay:
$15.82 per MCF of Natural Gas (925 BTU)
$17.10 per MCF of Natural Gas (1000 BTU)
$3.22 per gal of Diesel
$1.75 per gal of Propane

ENERGY REQUIRED TO LIFT THE WATER OF 1 FOOT

1 Acre-Foot Water = 43,560 Cubic Feet
1 Cubic Foot = 62.4 pounds
Energy required for 1 ft = 43,560 ft$^3$ x 62.40 lbs/ft$^3$ = 2,718,144 ft-lbs
1 hp = 33,000 ft-lbs/min
1 hp-hr = 33,000 ft-lbs/min x 60 min/hr = 1,980,000 ft-lbs/hr

Energy needed to pump 1 ac-ft of water at head of 1 foot
2,718,144 ft-lbs/1,980,000 ft-lbs/whp-hr = 1,373 whp-hr/ac-ft per foot of lift
**ELECTRICITY**

\[
\frac{1.373 \text{ whp – hr / ac – ft}}{0.885 \text{ whp – hr / kWh}} = 1.55 \text{ kWh / ac – ft per foot of lift}
\]

**NATURAL GAS (925 BTU)**

\[
\frac{1.373 \text{ whp – hr / ac – ft}}{61.7 \text{ whp – hr / kWh}} = 0.022 \text{ MCF / ac – ft per foot of lift}
\]

**NATURAL GAS (1000 BTU)**

\[
\frac{1.373 \text{ whp – hr / ac – ft}}{66.7 \text{ whp – hr / kWh}} = 0.020 \text{ MCF / ac – ft per foot of lift}
\]

**DIESEL**

\[
\frac{1.373 \text{ whp – hr / ac – ft}}{12.50 \text{ whp – hr / kWh}} = 0.10 \text{ gal / ac – ft per foot of lift}
\]

**PROPANE**

\[
\frac{1.373 \text{ whp – hr / ac – ft}}{12.50 \text{ whp – hr / kWh}} = 0.20 \text{ gal / ac – ft per foot of lift}
\]
Multiply these numbers by the total head in ft to obtain the **AMOUNT OF FUEL NECESSARY PER ACRE-FT OF WATER FOR A PARTICULAR LIFT**

Multiply these numbers by the total acre-ft of water to fulfil the crop water requirements (+ leaching, flushing, etc.) to obtain the **TOTAL FUEL NECESSARY TO PUMP WATER** (kWh, gal, MCF, etc.)

If we multiply the total fuel required by the unit fuel price, we obtain the **TOTAL COST TO PUMP WATER** ($$)
EXAMPLE 1

Alfalfa ET = 50 inches = 4.2 ft of water per season (SJV)
Area = 130 acres
Irrigation methods: Sprinkler (50 psi) Vs. SDI (20 psi)
Lift of water = 50 ft (from well to ground)

TDH\text{SPRINKLER}: 50 ft + 50 psi \times 2.31 \text{ ft/psi} = 165 \text{ ft}
TDH\text{SDI}: 50 ft + 20 psi \times 2.31 \text{ ft/psi} = 96 \text{ ft}
Total ac-ft \text{SPRINKLER} = 4.2/0.75 = 5.6 \text{ ac-ft}
Total ac-ft \text{SDI} = 4.2/0.90 = 4.6 \text{ ac-ft}

Diesel: 0.10 \text{ gal/ac-ft per foot of lift}

Sprinkler: 130 \text{ ac} \times 5.6 \text{ ac-ft} \times 165 \text{ ft} \times 0.10 \text{ gal/ac-ft} = 12,012 \text{ gal}
SDI = 130 \text{ ac} \times 4.6 \text{ ac-ft} \times 96 \text{ ft} \times 0.10 \text{ gal/ac-ft} = 5,740 \text{ gal}
Difference in fuel amount = 12,012 - 5,740 = 6,272 \text{ gal}
Cost of Diesel = $2.6 per gallon
Total saving = 6,272 \text{ gal} \times $2.6/gal = $16,307

<table>
<thead>
<tr>
<th>System</th>
<th>Eff.\text{A}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity</td>
<td>0.70</td>
</tr>
<tr>
<td>Drip &amp; SDI</td>
<td>0.90</td>
</tr>
<tr>
<td>Micro-sprinkler</td>
<td>0.80</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>0.75</td>
</tr>
</tbody>
</table>
EXAMPLE 2

Almond ET = 48 inches = 4.0 ft of water per season (SJV)
Area = 130 acres
Irrigation methods: Surface Irr. (5 psi) Vs. Drip (20 psi)
Lift of water = 150 ft (from well to ground)

TDH_{\text{SURFACE}}: 150 \text{ ft} + 5 \text{ psi} \times 2.31 \text{ ft/psi} = 161 \text{ ft}
TDH_{\text{DI}}: 150 \text{ ft} + 20 \text{ psi} \times 2.31 \text{ ft/psi} = 196 \text{ ft}
Total ac-ft_{\text{SURFACE}} = 4.0/0.70 = 5.7 \text{ ac-ft}
Total ac-ft_{\text{DI}} = 4.0/0.90 = 4.4 \text{ ac-ft}
Natural Gas_{925} : 0.022 \text{ MCF/ac-ft per foot of lift}

Surface Irr: 130 \text{ ac} \times 5.7 \text{ ac-ft} \times 161 \text{ ft} \times 0.022 \text{ MCF/ac-ft} = 2,624 \text{ MCF}
DI = 130 \text{ ac} \times 4.4 \text{ ac-ft} \times 196 \text{ ft} \times 0.022 \text{ MCF/ac-ft} = 2,466 \text{ MCF}
Difference in fuel amount = 2,624 – 2,466 = 158 \text{ MCF}
Price of Natural Gas = $3.39 per MCF
Total saving = 158 \text{ MCF} \times $3.39/\text{MCF} = $535.6

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</tr>
<tr>
<td>Sprinkler</td>
<td>0.75</td>
</tr>
</tbody>
</table>
2) SLOPING AREAS, OR DIFFERENT SIZES & DISTANCES
THANK YOU!