E³A: Pumping Plant Performance

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STEP 2

Steps in the Irrigation Series

The pumping plant is tasked with transferring water from a source (e.g., groundwater) to a field for irrigation. A typical pumping plant consists of a pump, engine (or electric motor), and gear drive and can be powered by several different energy sources. A more efficient pumping plant requires less energy to transfer water between the source and the field. Several factors can impact pumping plant efficiency. Kranz et al. (2010) listed the following as common causes for a pumping plant to operate inefficiently:

Found at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/nv/newsroom/stories/

Evaluating your pumping plant can help to identify efficiency issues and areas that can be improved, possibly identifying money saving improvements.

1. The pipeline is valved back at the well to meet pressure requirements
2. Increase in pumping lift due to mineral incrustation and/or iron bacteria clogging the well screen
3. Wear and tear on pump impeller over time or due to pumping sand
4. Improper impeller adjustment on deep-well turbine pumps
5. Modifying irrigation system without redesigning pumping plant
6. Mismatched system components (e.g., power unit is too large)
7. Power source is not operating at most efficient speed
8. Engine needs a tune-up
9. Improperly sized discharge column

Nebraska Pumping Plant Performance Criteria

The Nebraska Pumping Plant Performance Criteria (NPPPC) was developed to provide an estimate of the amount of work available per unit of energy consumed for a well-designed and managed water pumping plant. The amount of work accomplished by the pumping plant is referred to as water horsepower (WHP) and is calculated as:

$$WHP = \frac{Flow\ Rate \times [(Pressure \times 2.31) + Lift]}{3960}$$

(Equation 1)

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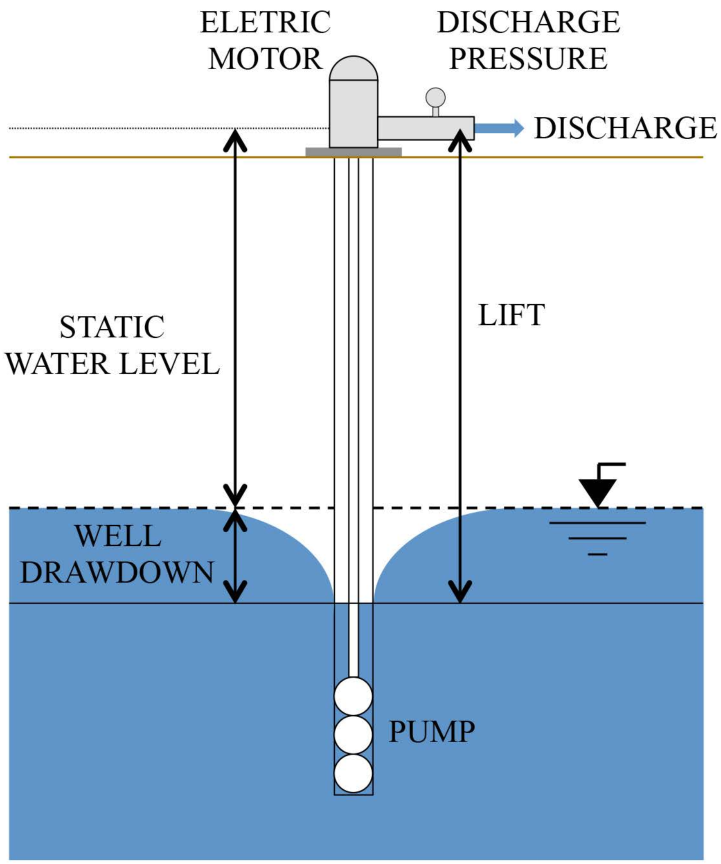

Figure 2. Diagram of a pumping plant and critical parameters needed to assess pumping plant efficiency.

where:

- WHP – Water horsepower produced by pumping plant
- Flow Rate – Discharge flow rate, gallons per minute (GPM)
- Pressure – Pump outlet pressure, pounds per square inch (psi)
- Lift – Distance between drawdown and outlet point, feet (ft)

These parameters are shown in relation to the pumping plant in Figure 2. As shown in Figure 2, lift is the vertical distance between the discharge point and the drawdown point and not between the discharge point and the static water table level or the location of the pump bowls. Lift can change over time if the drawdown level changes. Schroeder and Fischbach (1982) explained the necessary procedures to correctly measure pumping lift, discharge pressure, discharge flow rate, and the energy consumption of any particular pumping unit.

The energy performance (WHP-hr/unit) is obtained by dividing WHP by the energy use rate (unit/hr). The WHP-hr/unit values reported by the NPPPC for different energy sources, along with the average work available per unit of energy (HP-hr/unit) and the work accomplished by the power unit, including drive losses, per unit of energy (BHP-hr/unit) are shown in Table 2. Calculate pumping plant efficiency by dividing WHP-hr/unit by HP-hr/unit. For example, the NPPPC acceptable pumping plant efficiency (Epp) is 66% (Epp = 0.885 ÷ 1.34 = 0.66) for electricity and 23% (Epp = 12.5 ÷ 54.5 = 0.23) for diesel.

Performance Rating

The energy performance (WHP-hr/unit) values reported by NPPPC (Table 2) represent well-designed and managed/operated pumping plants and serve as a reference to evaluate existing pumping plants. The pumping plant's performance rating (PR) is the ratio of the existing and NPPPC WHP-hr/unit values and is calculated as:

$$PR(\%) = \left(\frac{Existing\ WHP-hr/unit}{NPPPC\ WHP-hr/unit}\right) \times 100\%$$

(Equation 2)

Table 2. Nebraska Pumping Plant Performance Criteria (NPPPC). Adapted from Martin et al. (2011) and Kranz (2010).

Energy source	Energy unit	[1]Horsepower-hr per unit	[2]Brake horsepower-hr per unit	[3,4]Water horsepower-hr per unit
Diesel	Gallon	54.5	16.7	12.5
LPG	Gallon	37.5	9.2	6.89
Gasoline	Gallon	49.1	11.5	8.66
Natural gas[5]	1,000 cu ft	393	88.9	66.7
Electricity	Kilowatt-hour	1.34	1.18[6]	0.885

[1] Average work available for different power sources per unit of energy
[2] Work accomplished by the power unit, including drive losses, per unit of energy
[3] Work produced by the pumping plant per unit of energy
[4] Based on 75% pump efficiency
[5] Assumes energy content of 1,000 BTU per cubic foot
[6] Assumes 88% electric motor efficiency

If the performance rating is at or greater than 100%, the system is operating at or above the expected performance level set by NPPPC; if it is below 100%, the system is using more energy than required. The pumping plant should be investigated to improve system performance and save energy and reduce unnecessary pumping costs. Morris and Lynne (2006) addressed and explained how to properly maintain irrigation pumps, motors, and engines for maximum efficiency. They also include descriptions and diagrams of recommended installations, checklists for maintenance tasks, and a troubleshooting guide.

Excess Energy Use

Determine the amount of excess energy used for pumping irrigation water with respect to the NPPPC by using the performance rating and total fuel consumed over a test period, calculated as:

$$Excess\ Energy = \left[\frac{(100\% - PR\%)}{100\%}\right] \times Amount\ of\ Fuel\ Used$$

(Equation 3)

Example:

- Performance rating = 89% (i.e., system is operating at 89% of the NPPPC)
- Fuel consumed = 3,500 gallons of diesel
- Test period = 1 year

$$Excess\ Energy = \left[\frac{(100\% - 89\%)}{100\%}\right] \times 3{,}500\ gallons\ per\ year$$

$$= 0.11 \times 3{,}500\ gallons\ per\ year$$

$$= 385\ gallons\ per\ year$$

The potential savings is the amount of excess energy consumed multiplied by the cost per unit of energy. For the above example, if diesel cost was $3.10 per gallon, the financial savings would be 385 gallons per year x $3.10 per gallon = $1,193.50 per year.

Economic Consideration

The potential financial savings can be thought of as the amount of money per year that can be invested to improve the performance of the pumping plant with the assumption of a fixed cost per unit of energy over the repayment period. The series present worth factor (SPWF) can be used to determine the present worth (i.e., total investment) of a series of equal annual payments (i.e., annual savings) for upgrades and repairs and is calculated as:

$$SPWF = \frac{(1+i)^n - 1}{i(1+i)^n}$$

(Equation 4)

where, i is the interest rate compounded annually (as decimal) and n is the number of equal annual payments. Table 3 provides SPWF values for various interest rates and repayment periods. The total investment is calculated by multiplying the financial savings (i.e., annual payment) by the SPWF.

Example continued:

Annual financial savings = $1,193.50
Interest rate = 6%
Repayment Period = 5 years

$$Investment = Annual\ Payment \times SPWF$$

$$= \$1{,}193.50 \times 4.21$$

$$= \$5{,}027$$

If the performance of the pumping plant can be improved to the NPPPC level with an investment of $5,027 or less, it is advised; if the cost of repairs exceeds $5,027, further investigation is needed to identify economically feasible means of improving the pumping plant.

Table 3. Series Present Worth Factor (SPWF) for equal annual payments.

Repayment	Annual Interest Rate (i)						
Period (n)	4%	5%	6%	7%	8%	9%	10%
3	2.78	2.72	2.67	2.62	2.58	2.53	2.49
4	3.63	3.55	3.47	3.39	3.31	3.24	3.17
5	4.45	4.33	4.21	4.10	3.99	3.89	3.79
6	5.24	5.08	4.92	4.77	4.62	4.49	4.36
7	6.00	5.79	5.58	5.39	5.21	5.03	4.87
8	6.73	6.46	6.21	5.97	5.75	5.53	5.33
9	7.44	7.11	6.80	6.52	6.25	6.00	5.76
10	8.11	7.72	7.36	7.02	6.71	6.42	6.14
11	8.76	8.31	7.89	7.50	7.14	6.81	6.50
12	9.39	8.86	8.38	7.94	7.54	7.16	6.81
13	9.99	9.39	8.85	8.36	7.90	7.49	7.10
14	10.56	9.90	9.29	8.75	8.24	7.79	7.37
15	11.12	10.38	9.71	9.11	8.56	8.06	7.61

Table 4. Estimated expected life (years) of various pumping plant components. Adapted from Duke (2007).

Component	Annual Hours of Operation			
	500	1000	2000	3000
Well	25	25	25	25
Pump	15	15	15	10
Gearhead	15	15	15	10
Drive shaft	15	15	7	5
Engine (heavy duty)	15	15	10	7
Engine (automotive)	5	3	2	1
Gas pipeline	25	25	25	25
Engine foundation	25	25	25	25
Electric motor	25	25	25	25
Electric controls and wiring	25	25	25	25

One should consider the expected life of the component(s) being updated or repaired when determining the repayment period length. In some cases, the manufacturer will provide an estimated expected life; however, if not, it should be estimated. Table 4 provides estimated life expectancy (years) for different components of a pumping plant under various annual hours of operation. Note the life expectancy of any component is also a function of the level and frequency of maintenance, quality of parts, and exposure to environmental conditions (e.g., shelter vs. no shelter).

References and Further Readings

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Notes

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