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REDUCING THE COST OF PUMPING IRRIGATION WATER

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Energy Use in Irrigation

Irrigation accounts for a large portion of the energy used in Nebraska agriculture. Analysis of data from the 2003 USDA Farm and Ranch Irrigation Survey shows that the average energy use for irrigating crops in Nebraska was equivalent to about 300 million gallons of diesel fuel annually. A number of irrigation wells have been installed since 2003, thus energy use today is even higher. While use varies depending on annual precipitation, average yearly energy consumption is equivalent to about 40 gallons of diesel fuel per acre irrigated.

The cost to irrigate a field is determined by the amount of water pumped and the cost to apply a unit (acre-inch) of water (Figure 1). Factors that determine pumping costs include those that are fixed for a given location (in the ovals in Figure1) and those that producers can influence. The four factors that producers can influence include: irrigation scheduling, application efficiency, efficiency of the pumping plant, and for center pivots the pumping pressure required for the system. Pumping costs can be minimized by concentrating on these factors.

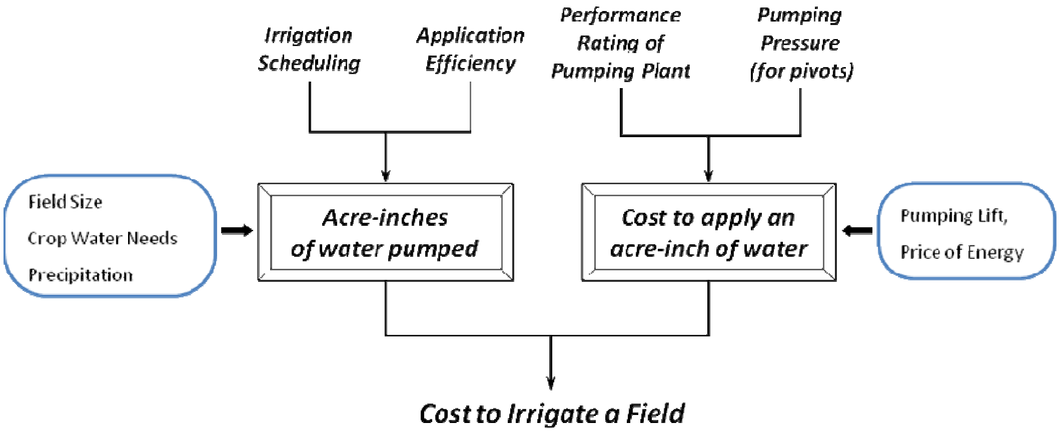

Figure 1. Diagram of factors affecting irrigation pumping costs

Irrigation scheduling can minimize the total volume of water applied to the field. Demonstration projects in central Nebraska have indicated that 1.5-2.0 inches of water can be saved by monitoring soil water content and estimating crop water use rates. The general idea is to maximize use of stored soil water and precipitation to minimize pumping.

Maximizing the efficiency of water application is a second way to conserve energy. Water application efficiency is a comparison between the depth of water pumped and the depth stored in the soil where it is available to the crop. Irrigation systems can lose water to evaporation in the air or directly off plant foliage. Water is also lost at the soil surface as evaporation or runoff. Excess irrigation and/or rainfall may also percolate through the crop root zone leading to deep percolation. For center pivots, water application efficiency is based largely on the sprinkler package. High pressure impact sprinklers direct water upward into the air and thus there is more opportunity for wind drift and in-air evaporation. In addition, high pressure impact sprinklers apply water to foliage for 20-40 minutes longer than low pressure spray heads mounted on drop tubes. The difference in application time results in less evaporation directly from the foliage for low pressure spray systems. Caution should be used so that surface runoff does not result with a sprinkler package. Good irrigation scheduling should minimize deep percolation.

Energy use can also be reduced by lowering the operating pressure of the irrigation system. One must keep in mind that lowering the operating pressure will reduce pumping cost per acre-inch, but reducing the pressure almost always results in an increased water application rate for a center pivot. The key is to ensure that the operating pressure is sufficient to eliminate the potential for surface runoff. Field soil characteristics, surface roughness, slope and tillage combine to control how fast water can be applied to the soil surface before surface runoff occurs. If water moves from the point of application, the savings in energy resulting from a reduction in operating pressure can be eliminated by the need to pump more water to ensure that all portions of the field receive at least the desired amount of water.

Finally, energy can be conserved by ensuring that the pumping plant is operating as efficiently as possible. Efficient pumping plants require properly matched pumps, systems and power sources. By keeping good records of the amount of water pumped and the energy used, you can calculate if extra money is being spent on pumping water and how much you can afford to spend to fix components that are responsible for increased costs.

This document describes a method to estimate the cost of pumping water and to compare the amount of energy used to that for a well maintained and designed pumping plant. The results can help determine the feasibility of repairing the pumping plant.

Energy Requirements

The cost to pump irrigation water depends on the type of energy used to power the pumping unit. Electricity and diesel fuel are used to power irrigation for about 75% of the land irrigated in Nebraska (Figure 2). Propane and natural gas are used on about 8 and 17% of the land respectively. Very little land is irrigated with gasoline powered engines.

The cost to pump an acre-inch of water depends on:

- The amount of work that can be expected from a unit of energy.
- The distance water is lifted from the groundwater aquifer or surface water.
- The discharge pressure at the pump,
- The efficiency of the pumping plant, and
- The cost of a unit of energy.

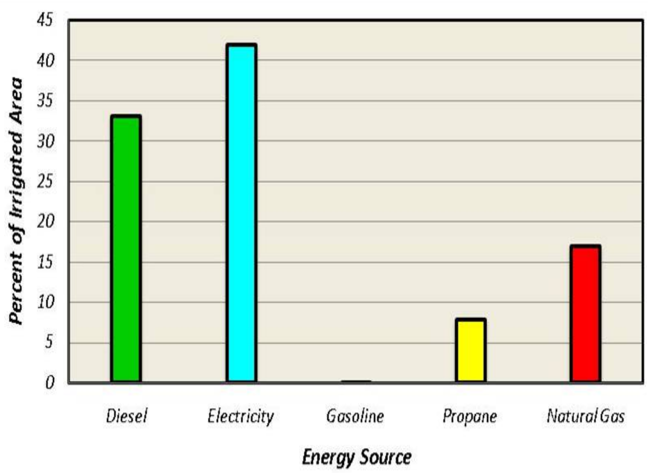

Figure 2. Percent of land irrigated in Nebraska by type of energy source (from USDA Farm and Ranch Irrigation Survey, 2003).

The amount of work produced per unit of energy depends on the source used to power the pump. For example one gallon of diesel fuel provides about 139,000 BTUs while propane provides about 95,500 BTUs/gallon. Clearly, more propane would be required to pump an acre-inch of water even if diesel and propane engines were equally efficient.

The Nebraska Pumping Plant Performance Criteria was developed to provide an estimate of the amount of work that can be obtained from a unit of energy by a well designed and managed pumping plant (Table 1). Values were developed from testing engines and motors to determine how much work (expressed as water horsepower hours) could be expected from a unit of energy for pumping plants that were well designed and maintained. The values reflect the amount of energy available per unit and how efficiently engines, motors and pumps operate.

Table 1. Amount of work produced per unit of energy used for a well designed and maintained pumping plant.

Energy Source	Value	Work Per Unit of Energy
Diesel	12.5	whp-hours / gallon
Gasoline	8.66	whp-hours / gallon
Propane	6.89	whp-hours / gallon
Natural Gas	61.7	whp-hours / 1000 ft^3
Electricity	0.885	whp-hours / kilowatt hour

whp stands for water horsepower

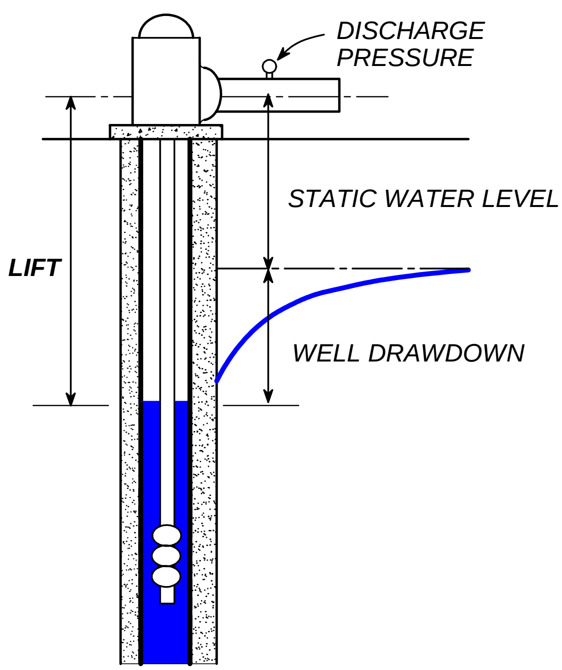

Figure 3. Diagram of pumping lift and discharge pressure measurements needed to assess pumping plant efficiency.

The pumping lift depends on the location of the water source relative to the elevation of the pump discharge. For groundwater the lift depends on the distance from the pump base to the water level when not pumping (static water level) plus the groundwater drawdown as shown in Figure 1. Note that the lift is not the depth of the well or the depth that the pump bowls are located in the well. The lift may increase over time if groundwater levels decline during the summer or over the years. It is best to measure the pumping lift directly but the value can be estimated from well registration information for initial estimates. Well registration information can be obtained from the Nebraska Department of Natural Resources at http://dnrdata.dnr.ne.gov/wellssql/

The discharge pressure depends on the pressure needed for the irrigation system, the elevation of the inlet to the irrigation system relative to the pump discharge, and the pressure loss due to friction in the piping between the pump and the irrigation system. It is best to measure the discharge pressure with a good gage near the pump base.

Pumping Plant Efficiency

The amount of energy required for a properly designed and maintained pumping plant to pump an acre-inch of water can be determined from Tables 2 and 3. For example, a producer who has a system with a pumping lift of 150 feet and

Table 2. Gallons of diesel fuel required to pump an acre-inch at a pump performance rating of 100%.

Lift feet	Pressure at Pump Discharge, psi						
	10	20	30	40	50	60	80
0	0.21	0.42	0.63	0.84	1.05	1.26	1.69
25	0.44	0.65	0.86	1.07	1.28	1.49	1.91
50	0.67	0.88	1.09	1.30	1.51	1.72	2.14
75	0.89	1.11	1.32	1.53	1.74	1.95	2.37
100	1.12	1.33	1.54	1.75	1.97	2.18	2.60
125	1.35	1.56	1.77	1.98	2.19	2.40	2.83
150	1.58	1.79	2.00	2.21	2.42	2.63	3.05
200	2.03	2.25	2.46	2.67	2.88	3.09	3.51
250	2.49	2.70	2.91	3.12	3.33	3.54	3.97
300	2.95	3.16	3.37	3.58	3.79	4.00	4.42
350	3.40	3.61	3.82	4.03	4.25	4.46	4.88
400	3.86	4.07	4.28	4.49	4.70	4.91	5.33

Table 3. Conversions for other energy sources.

Energy Source	Units	Multiplier
Diesel	gallons	1.00
Electricity	kilowatt-hours	14.12
Propane	gallons	1.814
Gasoline	gallons	1.443
Natural Gas	1000 cubic feet	0.2026

Table 4. Multiplier when pumping plant performance rating is less than 100%.

Rating, %	100	90	80	70	50	30
Multiplier	1.00	1.11	1.25	1.43	2.00	3.33

operates at a pump discharge pressure of 60 pounds per square inch (psi) would require 2.63 gallons of diesel fuel to apply an acre-inch of water. If the producer uses electricity the value of 2.63 should be multiplied by the factor in Table 3 to convert energy units. So, (2.63 x 14.12) = 37 kilowatt-hours would be needed per acre inch of water.

The amount of energy required for an actual pump depends on the efficiency of the pump and power unit. If the pumping plant is not properly maintained and operated, or if conditions have changed since the system was installed, the pumping plant may not operate as efficiently as listed in Table 2. The energy needed for an actual system is accounted for in the performance rating of the pumping plant. Table 4 can be used to determine the impact of a performance rating less than 100%. For a performance rating of 80% the multiplier is 1.25, so the amount of energy used would be 25% more than for a system operating as shown in Table 2. The amount of diesel fuel for the previous example would be (2.63 x 1.25) = 3.29 gallons per acre-inch of water.

Producers can use Tables 2-4 and their energy records to estimate the performance rating of the pumping plant and the amount of energy that could be saved if the pumping plant was repaired or if operation was adjusted to better match characteristics of the pump and power unit.

Producers can also use hourly performance to estimate how well their pumping plant is working. For the hourly assessment an estimate of the pumping lift, discharge pressure, flow rate from the well and the hourly rate of energy consumption are required. The acre-inches of water pumped per hour can be determined from in Table 5.

Table 5. Volume of water pumped per hour.

Pump Discharge, gpm	Water Pumped per hour, acre-inch/hr	Pump Discharge, gpm	Water Pumped per hour, acre-inch/hr
250	0.55	1250	2.76
300	0.66	1300	2.87
350	0.77	1350	2.98
400	0.88	1400	3.09
450	0.99	1500	3.31
500	1.10	1600	3.54
550	1.22	1700	3.76
600	1.33	1800	3.98
650	1.44	1900	4.20
700	1.55	2000	4.42
750	1.66	2100	4.64
800	1.77	2200	4.86
850	1.88	2400	5.30
900	1.99	2600	5.75
950	2.10	2800	6.19
1000	2.21	3000	6.63
1050	2.32	3200	7.07
1100	2.43	3400	7.51
1150	2.54	3600	7.96
1200	2.65	3800	8.40

The performance of the pumping plant (P_p) in terms of energy use per acre-inch of water is then the ratio of the amount of energy used per hour divided by the volume of water pumped per hour:

$$P_p = \frac{\text{hourly fuel use rate (in gallons / hour)}}{V_w \text{ (in acre - inches / hour)}}$$

For example, suppose a pump supplies 800 gallons per minute and the diesel engine burns 5.5 gallons of diesel fuel per hour. A flow rate of 800 gpm is equivalent to 1.77 acre-inches per hour (Table 5). The pumping plant performance is computed as 5.5 gallons of diesel per hour divided by 1.77 acre-inches of water per hour. This gives a performance of 3.11 gallons of diesel per acre-inch.

Suppose that the pumping lift is 150 feet and the discharge pressure is 60 psi. If the system operates at the Nebraska Pumping Plant Performance Criteria only 2.63 gallons of diesel per acre-inch would be required (Table 2). The pumping plant performance rating (R) would be:

$$R = \frac{100 \times \text{Value from Table 2}}{P_p} = \frac{100 \times 2.63}{3.11}$$

For this case the performance rating is 85 meaning that the system uses about 17% more diesel fuel than required for a system at the Nebraska Criteria. The multipliers in Table 2 can also be used with the hourly method for other energy sources.

Paying for Repairs

Energy savings from repairing the pumping plant should be compared to the ability to pay for the repairs. The money that can be paid for repairs is determined by the length of the repayment period and the annual interest rate. These values are used to compute the series present worth factor (Table 6). The breakeven investment that could be spent is the value of the annual energy savings times the series present worth factor.

Table 6. Series Present Worth Factor

Repayment Period, years	Annual Interest Rate					
	6%	7%	8%	9%	10%	12%
3	2.67	2.62	2.58	2.53	2.49	2.40
4	3.47	3.39	3.31	3.24	3.17	3.04
5	4.21	4.10	3.99	3.89	3.79	3.60
6	4.92	4.77	4.62	4.49	4.36	4.11
7	5.58	5.39	5.21	5.03	4.87	4.56
8	6.21	5.97	5.75	5.53	5.33	4.97
9	6.80	6.52	6.25	6.00	5.76	5.33
10	7.36	7.02	6.71	6.42	6.14	5.65
12	8.38	7.94	7.54	7.16	6.81	6.19
15	9.71	9.11	8.56	8.06	7.61	6.81
20	11.47	10.59	9.82	9.13	8.51	7.47
25	12.78	11.65	10.67	9.82	9.08	7.84

The series present worth factor represents the amount of money that could be repaid at the specified interest rate over the repayment period. For example, for an interest rate of 7% and a repayment period of 10 years each dollar of annual savings is equivalent to $7.02 today. Only $4.10 could be invested for each dollar of savings if the investment was to be repaid in 5 years rather than 10 years.

Examples

Some examples will illustrate the procedure to estimate potential from improving a pumping plant.

Example 1

Suppose a pivot was used on 130 acres to apply 13.5 inches of water. The pumping lift was about 125 feet and the discharge pressure was 50 psi. Energy use records for the past season show that 5500 gallons of diesel fuel were used. The average price of diesel fuel for the season was $3.00 per gallon.

The analysis of this example is illustrated in the worksheet in Figure 4. An efficient pumping plant would require about 3843 gallons of diesel fuel for the year (*i.e.,* 2.19 gallons/acre-inches times 1755 acre-inches of water). If a producer's records show that 5500 gallons were used to pump the water, then the performance rating would be (3843 / 5500) x 100 = 70%. This shows that 1657 gallons of diesel fuel could be saved if the pumping plant performance was improved. The annual savings in pumping costs would be the product of the energy savings times the cost of diesel fuel; *i.e.,* $3/gallon times 1657 gallons/year = $4971/year. If a 5-year repayment period and 9% interest were used, the series present worth factor would be 3.89. The breakeven repair cost would be $4971 × 3.89 = $19,337. If repair costs were less than $19,337 then repairs would be feasible. If costs were more than $19,337 the repairs may not be advisable at this time.

Example 2

This example represents a center-pivot field irrigated with a pump powered by electricity. Details of the system are also included in Figure 4. In this case the pumping lift is 175 feet which is not listed in Table 2. The lift of 175 feet is half way between 150 and 200 feet so the amount of diesel fuel per acre-inch of water is estimated as 2.44 gallons per acre-inch (*i.e.,* halfway between 150 and 200 feet). Since electricity is used to power the pumping plant the multiplier of 14.12 is used in row M of Figure 4. The calculations for the second example are similar to the first example for the rest of the information in Figure 4. This pumping plant has a performance rating of 88% and given the cost of electricity only about $3,770 could be spent for repairs.

Example 3

This example illustrates the application of the hourly method for a propane powered pumping plant. This system has a performance rating of 88% and based on Table 4 13% of the annual energy cost could be saved if the pumping plant was brought up to the Nebraska Criteria.

Summary

This publication demonstrates a method to estimate the potential for repairing pumping plants to perform at the Nebraska Pumping Plant Performance Criteria. Producers frequently have several questions regarding the procedure.

First they want to know ***"Can actual pumping plants perform at a level equal to the Criteria"***. Tests of 165 pumping plants in the 1980s indicated that up to 15% of the systems actually performed at a level above the Criteria. So producers can certainly achieve the standard.

The second question is ***"What level of performance can producers expect for their systems?"*** Tests on 165 systems in Nebraska during the 1980s produced an average performance rating of 77% which translates to an average energy savings of 30% by improving performance. Tests on 200 systems in North

Dakota in 2000 produced very similar results. These values illustrate that half of the systems in the Great Plains could be using much more energy than required. The simplified method can help determine if your system is inefficient.

The third issue focuses on ***"What should I do if the simplified method suggests that there is room for improving the efficiency?"*** You should first determine if the irrigation system is being operated as intended. You need to know if the pressure, lift and flow rate are appropriate for the irrigation system. For example, some systems were initially designed for furrow irrigation systems and are now used for center-pivot systems. If the conditions for the current system are not appropriate for the system you need to work with a well driller/pump supplier to evaluate the design of the system.

Sometimes the system is simply not operated properly. An example occurred where a center-pivot sprinkler package was installed that used pressure regulators with a pressure rating of 25 psi. However, the end gun on the pivot was not equipped with a booster pump so the main pump was operated at a pressure of 75 psi to pressurize the entire system just to meet the needs of the end gun. Since end guns only operate about half of the time the pump was actually pumping against the pressure regulators half of the time, wasting a significant amount of energy. The problem here was not the pump or the power unit but the sprinkler design and its operation.

We recommend that you periodically arrange with a well drilling company to test the efficiency of your pump. They conduct a test that determines pumping lift, discharge pressure and the efficiency of the pump for a range of conditions that you would expect for your system. They also use equipment to measure the power output of your engine or electric motor. While they don't usually measure the energy consumption rate the results of the test will tell you if the pump is performing efficiently. This provides an excellent reference for future analysis.

Figure 4. Pumping Cost Worksheet

		Pump/Field						
1. Known Information		*Annual Diesel Example*	*Annual Electric Example*	*Hourly Propane Example*				
A	Pumping lift, feet	***125***	***175***	***250***				
B	Pressure at pump discharge, psi	***50***	***40***	***55***				
C	Size of the irrigated field, acres	***130***	***128***	***130***				
D	Depth of irrigation applied, inches	***13.5***	***13***					
E	Amount of energy used to irrigate the field for the year	***5500***	***65,000***					
F	Type of energy source used to pump water	***Diesel***	***Electric***	***Propane***				
G	Cost of a unit of energy ($/gallon, $/kwh, etc.)	***$3.00***	***$0.07***	***$1.80***				
H	Annual interest rate, %	***9***	***7***					
I	Repayment period, years	***5***	***10***					
2. Annual Performance								
J	Gallons of diesel fuel @ standard to pump an acre-inch (from Table 2)	***2.19***	***2.44***	***3.44***				
K	Volume of water pumped, acre-inches: (multiply row C x row D)	***1755***	***1664***					
L	Gallons of diesel fuel needed at 100% Performance Rating (J x K)	***3843***	***4060***					
M	Multiplier for energy source (from Table 3)	***1***	***14.12***	***1.814***				
N	Energy used if at 100% pump rating (L x M)	***3843***	***57,327***					
O	Performance rating of pump (100 x N / E)	***70***	***88***					
P	Potential energy savings with repair, gallons, kWh, etc.: (E - N)	***1657***	***7673***					
Q	Annual cost savings, $ (G x P)	***$4,971***	***$537***					
R	Series present worth factor (Table 6)	***3.89***	***7.02***					
S	Breakeven repair investment (Q * R)	***$19,337***	***$3,770***					
3. Hourly Performance								
T	Pump discharge, gallons per minute			***700***				
U	Volume of water pumped per hour (Table 5), acre-inches/hour			***1.55***				
V	Energy use per hour if at 100% Performance Rating (J x M x U)			***9.65***				
W	Actual energy use rate (gallons/hour, 1000 cubic feet/hr, or kWh/hr)			***11.0***				
X	Pumping plant performance rating (100 x V /W)			***88***				