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Pumping Plant Performance

Derrel L. Martin
University of Nebraska-Lincoln, derrel.martin@unl.edu

William Kranz
University of Nebraska-Lincoln

Suat Irmak
University of Nebraska-Lincoln

Daran Rudnick
University of Nebraska-Lincoln, daran.rudnick@unl.edu

Chuck Burr
University of Nebraska-Lincoln, chuck.burr@unl.edu

See next page for additional authors

Authors

Derrel L. Martin, William Kranz, Suat Irmak, Daran Rudnick, Chuck Burr, and Steve Melvin

PUMPING PLANT PERFORMANCE

Derrel Martin, William Kranz, Suat Irmak,
Daran Rudnick, Charles Burr, Steven Melvin
Biological Systems Engineering
University of Nebraska-Lincoln
Lincoln, NE

ENERGY USE IN IRRIGATION

Irrigation accounts for a large portion of the energy used in Nebraska agriculture. Analysis of data from the 2008 USDA Farm and Ranch Irrigation Survey shows that the average energy use for irrigating crops in Nebraska would be equivalent to about 340 million gallons of diesel fuel annually if all pumps were powered with diesel engines. While use varies annually, average yearly energy consumption is equivalent to about 40 gallons of diesel fuel per acre irrigated.

The cost to irrigate a field depends on the volume 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 Figure 1) and those that producers can influence. The factors that producers can influence include: irrigation scheduling, application efficiency, efficiency of the pumping plant, and the pumping pressure system. Pumping costs can be minimized by concentrating on these factors. Irrigators may also consider changing the type of energy used to power irrigation if they determine that one source provides a long-term advantage.

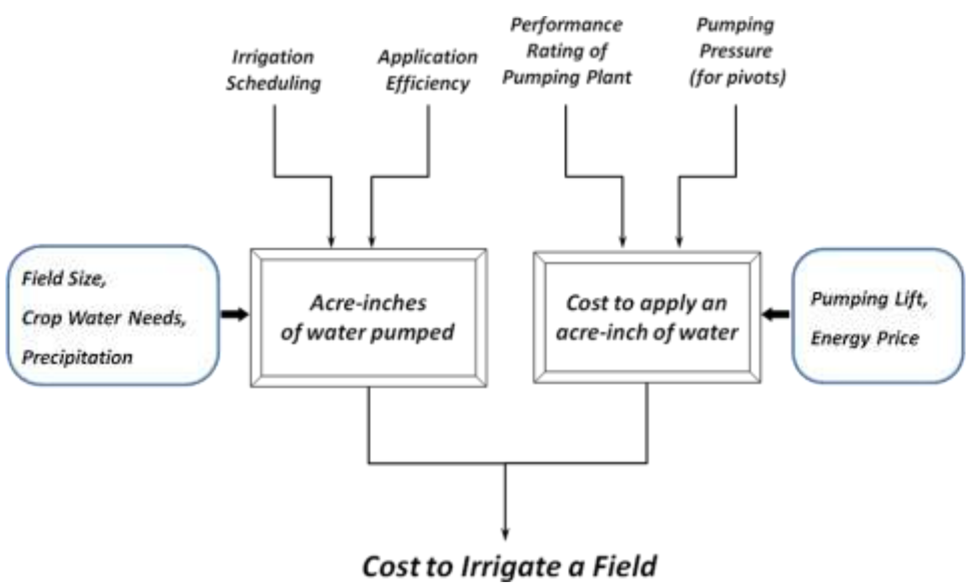

Figure 1. Factors affecting irrigation pumping costs.

Irrigation scheduling can minimize the total volume of water applied to the field. Demonstration projects in central Nebraska illustrated monitoring soil water and estimating crop water use could reduce pumpage by about 2.0 inches annually. More comprehensive scheduling of irrigation could potentially reduce pumpage even more. The goal is to maximize use of stored soil water and precipitation to minimize pumping.

Improving 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.

Lowering the operating pressure of an irrigation system reduces the pumping cost per acre-inch but often results in an increased water application rate for center pivot systems. 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 is counterbalanced 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 discover if extra money is being spent on pumping the water and how much you can afford to spend to fix components that are responsible for increased costs.

This paper describes a method to estimate the cost of pumping water and compares the amount of energy used by a well-maintained and designed pumping plant. The results can help determine the feasibility of repairing the pumping plant. Methods to compare energy sources are also presented.

ENERGY REQUIREMENTS

The cost to pump irrigation water depends on the type of energy used to power the pumping unit. Electricity and diesel fuel power pumps for about 82% of the land irrigated in Nebraska (Table 1), while propane and natural gas account for about 8 and 10% of the land respectively. Very few pumps utilize gasoline engines.

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

- Work produced per unit of energy consumed,
- Distance water is lifted from the groundwater aquifer or surface water source,
- Discharge pressure at the pump,
- Performance rating of the pumping plant, and
- Cost of a unit of energy.

Table 1. Distribution of irrigated pumps by type of energy source (USDA_FRIS. 2013).

State	Diesel and biodiesel fuel	Electricity	Gasoline, ethanol, and blends	LP gas, Propane, and Butane	Natural Gas	Total
			Number of Pumps			
Colorado	825	12387	211	45	405	13873
Kansas	4560	8558	258	861	9900	24137
Nebraska	21893	46031	174	6311	8609	83018
Total	27278	66976	643	7217	18914	121028
			Percent of Irrigation Pumps			
Colorado	5.9%	89.3%	1.5%	0.3%	2.9%	100%
Kansas	18.9%	35.5%	1.1%	3.6%	41.0%	100%
Nebraska	26.4%	55.4%	0.2%	7.6%	10.4%	100%

The amount of work produced per unit of energy depends on the source used to power the pump (Table 2). One gallon of diesel fuel generates about 139,000 BTU of energy if completely burned. The energy content can also be expressed as the horsepower-hours of energy per gallon of fuel (*i.e.,* 54.5 hp-hr/gallon). Not all of the energy contained in the fuel can be converted to productive work when the fuel is burned in an engine. The Nebraska Pumping Plant Performance Criteria provides an estimate of the amount of work attainable from a unit of energy by a well designed and managed pumping plant (Table 2). Values originate from testing engines and motors to determine how much work expected from a unit of energy. An average efficiency for the pump and drive system for well-designed and maintained pumping plants defines the amount of work that could be expected from a "good" pumping plant. The overall performance of the engine/motor and pump system is expressed as water horsepower hours (whp-hr). Research conducted to develop the Nebraska Pumping Plant Criteria showed that diesel engines produced about 16.7 hp-hr of work per gallons of diesel and that good pumping plants produce about 12.5 whp-hr/gallon of diesel fuel. The performance of the engine and pumping plant systems can also be expressed as an efficiency, *i.e.,* the ratio of the work done compared to the energy in the fuel. Results show that a diesel engine that meets the Nebraska Pumping Plant Criteria is only about 30% efficient and that the overall efficiency is only about 23%. Diesel engines are more efficient than spark engines (Table 2).

The amount of energy required for a specific system depends on the location of the water source relative to the elevation of the pump discharge. For groundwater, the pumping 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 2. 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 years. It is best to measure the pumping lift directly but the value can be estimated from well registration information for initial estimates. The Nebraska Department of Natural Resources at *http://dnrdata.dnr.ne.gov/wellssql/* provides well registration in Nebraska.

Table 2. Energy Content of Fuels for Powering Irrigation Engines‡

Energy Source	Average Energy Content		Nebraska Pump Plant Criteria		Engine or Motor Efficiency, %	Pumping Plant Conversion, %
	BTU	horsepower hour	Engine or Motor Performance, hp-hr/unit	Pumping Plant Performance, whp-hr/unit†		
1 gallon of diesel fuel	138,690	54.5	16.7	12.5	31	23
1 gallon of gasoline	125,000	49.1	11.5	8.66	23	18
1 gallon of liquefied petroleum gas (LPG)	95,475	37.5	9.20	6.89	25	18
1 thousand cubic foot of natural gas	1,020,000	401	82.2	61.7	21	15
1 therm of natural gas	100,000	39.3	8.06	6.05	21	15
1 gallon of ethanol Ƭ	84,400	33.2	*7.80*	*5.85*	X	X
1 gallon of gasohol (10% ethanol, 90% gasoline)	120,000	47.2	*11.08*	*8.31*	X	X
1 kilowatt-hour of electrical energy	3,412	1.34	1.18	0.885	88	66

‡ Conversions: 1 horsepower = 0.746 kilowatts, 1 kilowatt-hour = 3412 BTU, 1 horsepower-hour = 2,544 BTU

† Assumes an overall efficiency of 75% for the pump and drive.

Ƭ Nebraska Pumping Plant Criteria for fuels containing ethanol were estimated based on the BTU content of ethanol and the performance of gasoline engines.

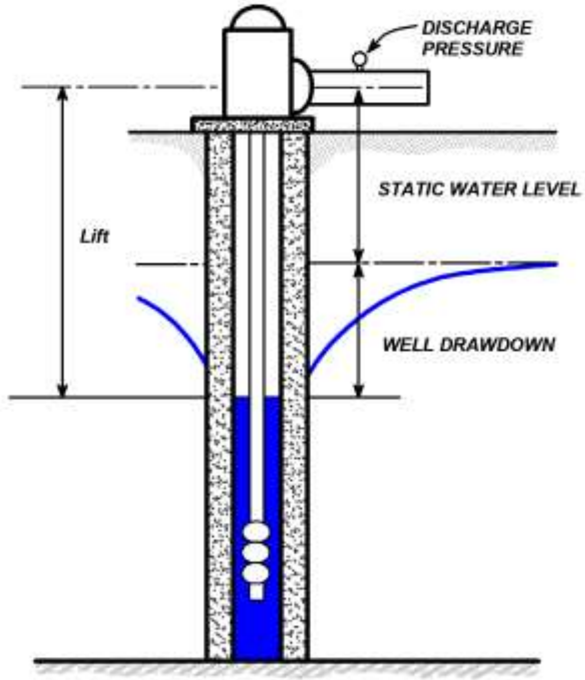

Figure 2. Diagram of pumping lift and discharge pressure measurements needed to assess pumping performance.

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 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 (Table 2). If the producer uses electricity, the value of 2.63 should be multiplied by the factor in Table 3 to convert energy units. So, for electricity (2.63 x 14.12) = 37 kilowatt-hours would be needed per acre-inch of water.

The amount of energy required for a pump depends on the efficiency of the pump and power unit. The pumping plant may not operate as efficiently as listed in Table 2 if the pumping plant is not properly maintained and operated, or if conditions have changed since the system was installed. The energy needed for an actual system is accounted for in the performance rating of the pumping plant. Table 4 provides the impact of a performance rating less that 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 3. 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 for their 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 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 Table 5.

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

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

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 3.11 gallons of diesel per acre-inch.

Suppose that the pumping lift is 150 feet and the discharge pressure is 60 psi for this example. 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:

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

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 3 also apply to 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 is the value of the annual energy savings times the series present worth factor.

The series present worth factor represents the breakeven amount of money that could be invested today for an annual savings of one dollar 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 rather than 10 years.

Table 3. Gallons of diesel fuel required to pump an acre-inch at a performance rating of 100%.

Lift	Pressure at Pump Discharge, psi						
feet	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

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

Table 5. Volume of water pumped per hour.

Pump Discharge,	Water Pumped per Hour,	Pump Discharge,	Water Pumped per
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

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

EXAMPLES

Example 1

Suppose a pivot irrigated 130 acres and applied 13.5 inches of water annually. 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 worksheet in Figure 3 illustrates the analysis of this example. 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

Example 2 represents a center-pivot field irrigated with a pump powered by electricity. Details of the system are also included in Figure 5. 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 3. The calculations for the second example are similar to the first example for the rest of the information in Figure 3. 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 about 13% of the annual energy cost could be saved if the pumping plant was brought up to the Nebraska Criteria.

COMPARING ENERGY SOURCES

The optimal type of energy for powering irrigation engines depends on the long-term relative price of one energy source to another. Energy prices have varied considerably over time. The nominal cost of energy per million BTUs is illustrated in Figure 4 for the types used to power irrigation systems for the period from 1970 through 2006. These results show that electricity was expensive relative to other energy sources from about 1983 through about 2000. Electricity has become more favorable especially recently when fossil fuels prices have increased rapidly. While diesel fuel once was very economical the situation has recently changed.

Two methods can be used to analyze power source alternatives for irrigation. The previous section illustrated how to determine the amount one could afford to pay through annual energy savings if one changed from an energy source to another type. Tom Dorn has developed a more detailed analysis based on the average annual ownership cost (http://lancaster.unl.edu/ag/Crops/irrigate.shtml). A demonstration of the technique is illustrated to compare diesel and electricity as energy sources for a typical center pivot. Representative costs are included in Figure 5 for an electrically powered pivot and in Figure 6 for a pivot powered with a diesel engine. The cost for the electric motor should include any extra expenses for control panels and to bring three-phase service to the motor. The diesel engine should include the cost of the fuel tank and an electric generator if one is not present. The costs listed in the figures are approximate values and local conditions should be use for specific comparisons.

Results of using the spreadsheet to compare the total annual cost of an electrically powered and a diesel powered irrigation system are in Table 7 for a range of electricity and diesel fuel prices. The annual savings is the difference between the annual costs for diesel, minus the cost for an electrically powered system. The results show that electricity is generally preferred except when diesel is less than 2.25 $/gallon and electrical rates are above 8¢/kWh. If the price of electricity is 6¢/kWh and diesel fuel is $2.25 per gallon, then switching to electricity could save over $3,000 annually as long as service can be brought to the field. Again, these are representative costs and producers should analyze their unique situation.

SUMMARY

This publication demonstrates methods to estimate the potential for repairing pumping plants to perform at the Nebraska Pumping Plant Performance Criteria and the annual cost for varying energy sources. Producers frequently have several questions regarding the procedures.

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 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 could be 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 operates as intended. You need to know if the pressure, lift and flow rate are appropriate for the irrigation system. For example, some systems initially designed for furrow irrigation systems and now supply 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 operates improperly. 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 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 you 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 you engine or electric motor. While they do not 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.

1. Known Information		Pump/Field						
		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***				

Figure 3. Pumping plant performance examples.

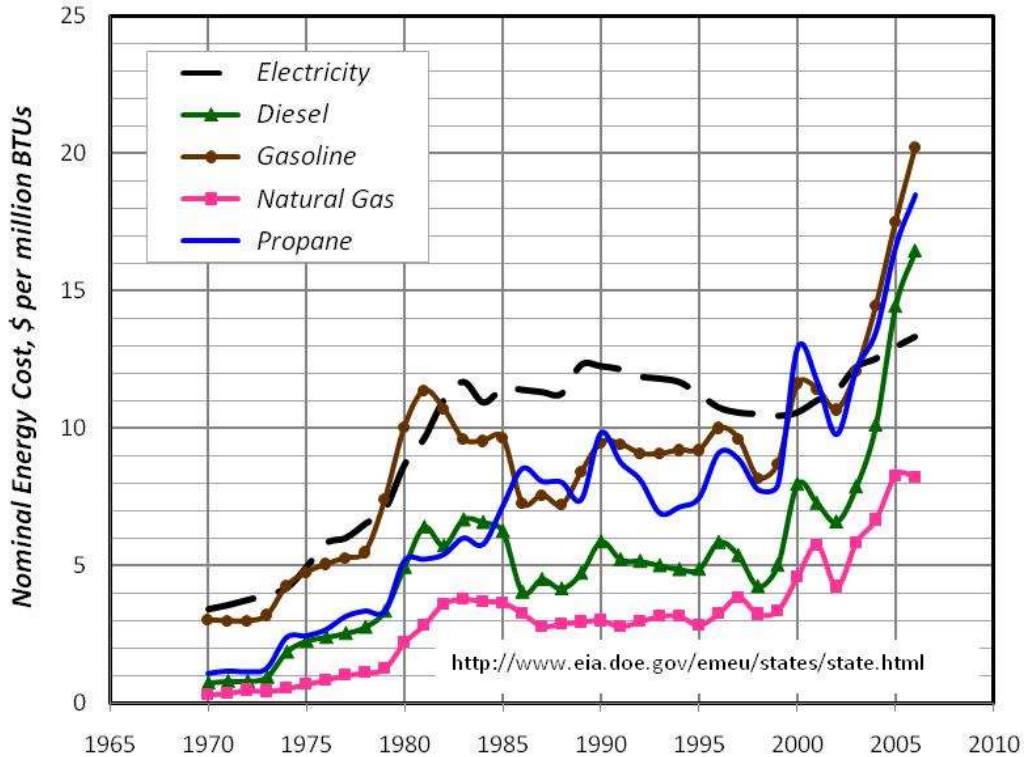

Figure 4. Historical prices of energy.

Annualized Cost of Owning and Operating an Irrigation System

Center Pivot with Electric Pump Motc — Written by: Tom Dorn, Extension Educator UNL-IANR Lancaster County, NE revised 02/02/2009

Select Distribution System	Pivot			
Acres Irrigated	130			
Pumping water level, ft.	150			
System Pressure, PSI	50			
Gross Depth applied, inch	12			
Select Power Unit Type	Electricity			
$/kW-h	$0.060			
Labor Chrg, $/hour	$15.00			
Irrigation District, $/ac-ft	0			
Return on Invest. (R.O.I), %	6			
Drip Oil, $/gal	$4.50			
Increase in Property Tax Due to Irrig.Development, $/ac				$0.00
Annual Elec Hookup Cost	$2,500	HP= 100		$/HP= $25.00

Note: Users are encouraged to replace values in blue font with values that represent their unique situation.

Select Distribution system and energy source for the pump motor from pull down menus.

Component				Ownership Costs			Operating Costs				
	Initial Cost	Life	Salvage[4]	R.O.I.	Insurance + tax	Depr	Repairs[2]	Oper. labor	Electricity	Energy $[1]	Total Costs
Irrigation Well	$16,500	25	($825)	$491	$165	$693	$215	$23	Kw-hour	kW+Hookup	$1,587
Irrigation Pump	$11,163	18	$558	$369	$112	$589	$340	$94		$/kW-h	$1,504
Gear Head	$0	15	$0	$0	$0	$0	$0	$0		$0.11	$0
Pump Base, etc.	$1,100	25	$55	$36	$11	$42	$17	$23			$129
Electric Motor& Switches	$8,500	30	$425	$276	$170	$269	$550	$351	53,182	$5,691	$7,307
Center Pivot System	$52,000	20	$2,600	$1,712	$1,040	$2,470	$2,028	$702		$70	$8,022
			$0	$0	$0	$0	$0	$0		$0	$0
											$0
Add'l Property Tax					$0						$0
Totals	$89,263		$2,813	$2,884	$1,498	$4,063	$3,150	$1,193		$5,761	$18,549

	Ownership Costs	Operating Costs	Total Costs
Total annual $	$8,445	$10,104	$18,549
Annual $/ Acre	$64.96	$77.72	$142.68
$/ac-in	$5.41	$6.48	$11.89

1 Energy Cost assumes operating at 100% of the NPC. Hookup charge added for Electric Units.
2 Drip oil added to repair costs. For internal combustion engines, 5% o energy costs added to repair costs for oil, filters, and lube.
3 Energy Cost for Center Pivot assumes 7/8 hp-h per acre inch of water delivered. Other systems require no additional energy for distribution
4 End of life salvage value 5% of purchase price except for irrigation well.
End of life cost for well = 5% to plug the well.

Figure 5. Detailed analysis for an electrically powered center-pivot irrigated field with the conditions shown.

Annualized Cost of Owning and Operating an Irrigation System

Center Pivot with Diesel Engine

Written by: Tom Dorn, Extension Educator UNL-IANR Lancaster County, NE revised 02/02/2009

Select Distribution System	Pivot
Acres Irrigated	130
Pumping water level, ft.	150
System Pressure, PSI	50
Gross Depth applied, inches	12
Select Power Unit Type	Diesel
$/Gallon	$2.250
Labor Chrg, $/hour	$15.00
Irrigation District, $/ac-ft	0
Return on Invest. (R.O.I), %	5
Drip Oil, $/gal	$4.50
Increase in Property Tax Due to Irrig.Development, $/ac	$0.00

Note: Users are encouraged to replace all values in blue font with values that represent their unique situation.

Select Distribution system and energy source for the pump motor from pull down menus.

Component				Ownership Costs			Operating Costs				
	Initial Cost	Life	Salvage[4]	R.O.I.	nsurance + tax	Depr	Repairs[2]	Oper. labor	Diesel Gallons	Energy $[1]	Total Costs
Irrigation Well	$16,500	25	($825)	$409	$165	$693	$215	$23			$1,505
Irrigation Pump	$11,163	18	$558	$308	$112	$589	$340	$94			$1,442
Gear Head	$2,800	15	$140	$78	$28	$177	$36	$23			$343
Pump Base, etc.	$1,100	25	$55	$30	$11	$42	$17	$23			$123
Diesel Engine & Tank	$11,500	12	$575	$325	$230	$910	$782	$351	3,765	$8,472	$11,070
Center Pivot System	$52,000	20	$2,600	$1,427	$1,040	$2,470	$2,028	$0		$185	$7,150
			$0	$0	$0	$0	$0	$0		$0	$0
											$0
Add'l Property Tax					$0						$0
Totals	$95,063		$3,103	$2,576	$1,586	$4,882	$3,419	$515		$8,657	$21,634

	Ownership Costs	Operating Costs	Total Costs
Total annual $	$9,044	$12,591	$21,634
Annual $/ Acre	$69.57	$96.85	$166.42
$/ac-in	$5.80	$8.07	$13.87

1 Energy Cost assumes operating at 100% of the NPC. Hookup charge added for Electric Units.
2 Drip oil added to repair costs. For internal combustion engines, 5% of energy costs added to repair costs for oil, filters, and lube.
3 Energy Cost for Center Pivot assumes 7/8 hp-h per acre inch of water . delivered. Other systems require no additional energy for distribution
4 End of life salvage value 5% of purchase price except for well.
End of life cost for well = 5% to plug the well.

Figure 6. Detailed analysis for a center-pivot irrigated field powered with diesel fuel for the field conditions shown.

Table 7. Annual Savings by Using Electricity

Electricity		Diesel Fuel Cost, $ / gallon			
		1.75	2.00	2.25	2.50
Price, $ / kWh	Total Annual Costs	$19,616	$20,625	$21,634	$22,643
0.06	$18,549	$1,067	$2,076	$3,085	$4,094
0.07	$19,119	$497	$1,506	$2,515	$3,524
0.08	$19,689	-$73	$936	$1,945	$2,954
0.09	$20,259	-$643	$366	$1,375	$2,384
0.10	$20,829	-$1,213	-$204	$805	$1,814

APPENDICES. WORKSHEETS FOR PUMPING PLANT PERFORMANCE

The following worksheets provide condensed analysis of pumping plant performance and investment alternatives for specific energy sources. These forms reduce some calculations required for the analysis and provide a record system performance for future considerations.

ESTIMATING IRRIGATION PUMPING COSTS
for Diesel Engines

1. Determine gallons of diesel fuel needed to pump an acre-inch if pump has a 100% performance rating.

	System				
	Example	1	2	3	4
Pressure at Pump Discharge,, psi	***50***				
Pumping Lift, feet	***125***				
Diesel Needed Per Acre-Inch At 100% Rating	***2.19***				

Gallons of diesel fuel required to pump an acre-inch of water

	Discharge Pressure, psi							
Lift	10	20	30	40	50	60	70	80
0	0.21	0.42	0.63	0.84	1.05	1.26	1.47	1.69
25	0.44	0.65	0.86	1.07	1.28	1.49	1.70	1.91
50	0.67	0.88	1.09	1.30	1.51	1.72	1.93	2.14
75	0.89	1.11	1.32	1.53	1.74	1.95	2.16	2.37
100	1.12	1.33	1.54	1.75	1.97	2.18	2.39	2.60
125	1.35	1.56	1.77	1.98	2.19	2.40	2.61	2.83
150	1.58	1.79	2.00	2.21	2.42	2.63	2.84	3.05
175	1.81	2.02	2.23	2.44	2.65	2.86	3.07	3.28
200	2.03	2.25	2.46	2.67	2.88	3.09	3.30	3.51
250	2.49	2.70	2.91	3.12	3.33	3.54	3.75	3.97
300	2.95	3.16	3.37	3.58	3.79	4.00	4.21	4.42
350	3.40	3.61	3.82	4.03	4.25	4.46	4.67	4.88
400	3.86	4.07	4.28	4.49	4.70	4.91	5.12	5.33

2. Field Information:		Example	1	2	3	4
Annual Depth of Irrigation Applied, inches		***13.5***				
Field Size, acres		***130***				
Volume of Water Pumped, acre-inches		***1755***				
3. Diesel Fuel Needed if at 100% of Performance Rating (multiply gallons per ac-inch times volume pumped)		***3843***				
4. Energy Actually Used Last Year, gallons		***4800***				
5. Energy Savings (Subtract 3 from 4), gallons		***957***				
6. Potential Cost Savings	Cost $ / gallon	***3.00***				
	Annual Cost Savings, $	***2871***				

Notes:

ESTIMATING IRRIGATION PUMPING COSTS
for Electric Motors

1. Determine kilowatt-hours of electricity needed to pump an acre-inch if at 100% performance rating.

	System			
	Example	1	2	3
Pressure at Pump Discharge, psi	***50***			
Pumping Lift, feet	***125***			
Electricity per acre-inch if at 100% performance rating	***30.98***			

Kilowatt-hours per acre-inch of water pumped

	Discharge Pressure, psi							
Lift	10	20	30	40	50	60	70	80
0	2.98	5.95	8.93	11.90	14.88	17.85	20.83	23.80
25	6.20	9.17	12.15	15.12	18.10	21.07	24.05	27.03
50	9.42	12.39	15.37	18.34	21.32	24.29	27.27	30.25
75	12.64	15.61	18.59	21.56	24.54	27.51	30.49	33.47
100	15.86	18.83	21.81	24.78	27.76	30.73	33.71	36.69
125	19.08	22.05	25.03	28.00	30.98	33.96	36.93	39.91
150	22.30	25.27	28.25	31.22	34.20	37.18	40.15	43.13
175	25.52	28.49	31.47	34.44	37.42	40.40	43.37	46.35
200	28.74	31.71	34.69	37.67	40.64	43.62	46.59	49.57
250	35.18	38.15	41.13	44.11	47.08	50.06	53.03	56.01
300	41.62	44.60	47.57	50.55	53.52	56.50	59.47	62.45
350	48.06	51.04	54.01	56.99	59.96	62.94	65.91	68.89
400	54.50	57.48	60.45	63.43	66.40	69.38	72.35	75.33

2. Field Information:	Example	1	2	3
Annual Depth of Irrigation Applied, inches	***13.5***			
Field Size, acres	***130***			
Volume of Water Pumped, acre-inches	***1755***			

3. Electricity Needed if at 100% Performance Rating (multiply kW-hr per acre-inch times volume of water pumped)	***54,369***			
4. Energy Actually Used Last Year, kW-hr	***68,000***			
5. Energy Savings (Subtract 3 from 4), kW-hr	***13,631***			
6. Potential Cost Savings — Cost $ / kilowatt-hour	***0.07***			
Annual Savings, $	***954***			

Notes:

1. Determine gallons of gasoline needed to pump an acre-inch if pump has a 100% performance rating.

	System			
	Example	1	2	3
Pressure at Pump Discharge,, psi	***50***			
Pumping Lift, feet	***125***			
Gasoline Needed Per Acre-Inch At 100% Rating	***3.17***			

Gallons of gasoline required per acre-inch of water pumped.

	Discharge Pressure, psi							
Lift	10	20	30	40	50	60	70	80
0	0.30	0.61	0.91	1.22	1.52	1.82	2.13	2.43
25	0.63	0.94	1.24	1.55	1.85	2.15	2.46	2.76
50	0.96	1.27	1.57	1.87	2.18	2.48	2.79	3.09
75	1.29	1.60	1.90	2.20	2.51	2.81	3.12	3.42
100	1.62	1.92	2.23	2.53	2.84	3.14	3.45	3.75
125	1.95	2.25	2.56	2.86	3.17	3.47	3.77	4.08
150	2.28	2.58	2.89	3.19	3.50	3.80	4.10	4.41
175	2.61	2.91	3.22	3.52	3.82	4.13	4.43	4.74
200	2.94	3.24	3.55	3.85	4.15	4.46	4.76	5.07
250	3.60	3.90	4.20	4.51	4.81	5.12	5.42	5.72
300	4.25	4.56	4.86	5.17	5.47	5.77	6.08	6.38
350	4.91	5.22	5.52	5.82	6.13	6.43	6.74	7.04
400	5.57	5.87	6.18	6.48	6.79	7.09	7.39	7.70

2. Field Information:		Example	1	2	3
Annual Depth of Irrigation Applied, inches		***13.5***			
Field Size, acres		***130***			
Volume of Water Pumped, acre-inches		***1755***			
3. Gasoline Needed if at 100% of Performance Rating (multiply gallons per acre-inch times volume pumped)		***5556***			
4. Energy Actually Used Last Year, gallons		***7000***			
5. Energy Savings (Subtract 3 From 4), gallons		***1444***			
6. Potential Cost Savings	Cost $ / gallon	***2.75***			
	Annual Cost Savings, $	***3971***			

Notes:

1. Determine amount of natural gas (1000 ft^3) needed to pump an acre-inch if at 100% performance rating.

	System: Example	1	2	3
Pressure at Pump Discharge,, psi	***50***			
Pumping Lift, feet	***125***			
Natural Gas Needed Per Acre-Inch At 100% Rating (Table 1)	***0.444***			

Thousand cubic feet of natural gas per acre-inch of water pumped

	Discharge Pressure, psi							
Lift	10	20	30	40	50	60	70	80
0	0.043	0.085	0.128	0.171	0.213	0.256	0.299	0.341
25	0.089	0.132	0.174	0.217	0.260	0.302	0.345	0.388
50	0.135	0.178	0.220	0.263	0.306	0.348	0.391	0.434
75	0.181	0.224	0.267	0.309	0.352	0.395	0.437	0.480
100	0.227	0.270	0.313	0.355	0.398	0.441	0.484	0.526
125	0.274	0.316	0.359	0.402	0.444	0.487	0.530	0.572
150	0.320	0.363	0.405	0.448	0.491	0.533	0.576	0.619
175	0.366	0.409	0.451	0.494	0.537	0.579	0.622	0.665
200	0.412	0.455	0.498	0.540	0.583	0.626	0.668	0.711
250	0.505	0.547	0.590	0.633	0.675	0.718	0.761	0.803
300	0.597	0.640	0.682	0.725	0.768	0.810	0.853	0.896
350	0.689	0.732	0.775	0.817	0.860	0.903	0.945	0.988
400	0.782	0.824	0.867	0.910	0.952	0.995	1.038	1.081

2. Field Information:	Example	1	2	3
Annual Depth of Irrigation Applied, inches	***13.5***			
Field Size, acres	***130***			
Volume of Water Pumped, acre-inches	***1755***			
3. Natural Gas Needed if at 100% Performance Rating (multiply 1000 ft^3 per acre-inch times volume pumped)	***780***			
4. Energy Actually Used Last Year, 1000 ft^3	***1000***			
5. Energy Savings (Subtract 3 From 4), 1000 ft^3	***220***			
6. Potential Cost Savings — Cost $ / 1000 ft^3	***9.00***			
Annual Cost Savings, $	***1980***			

Notes:

ESTIMATING IRRIGATION PUMPING COSTS
for Propane Engines

1. Determine gallons of propane needed to pump an acre-inch if pump has a 100% performance rating.

	System			
	Example	1	2	3
Pressure at Pump Discharge,, psi	***50***			
Pumping Lift, feet	***125***			
Propane Needed Per Acre-Inch At 100% Rating (Table 1)	***3.98***			

Gallons of propane required to pump an acre-inch of water

	Discharge Pressure, psi							
Lift	10	20	30	40	50	60	70	80
0	0.38	0.76	1.15	1.53	1.91	2.29	2.68	3.06
25	0.80	1.18	1.56	1.94	2.32	2.71	3.09	3.47
50	1.21	1.59	1.97	2.36	2.74	3.12	3.50	3.88
75	1.62	2.01	2.39	2.77	3.15	3.53	3.92	4.30
100	2.04	2.42	2.80	3.18	3.57	3.95	4.33	4.71
125	2.45	2.83	3.21	3.60	3.98	4.36	4.74	5.13
150	2.86	3.25	3.63	4.01	4.39	4.78	5.16	5.54
175	3.28	3.66	4.04	4.42	4.81	5.19	5.57	5.95
200	3.69	4.07	4.46	4.84	5.22	5.60	5.98	6.37
250	4.52	4.90	5.28	5.67	6.05	6.43	6.81	7.19
300	5.35	5.73	6.11	6.49	6.87	7.26	7.64	8.02
350	6.17	6.56	6.94	7.32	7.70	8.08	8.47	8.85
400	7.00	7.38	7.76	8.15	8.53	8.91	9.29	9.68

2. Field Information:	Example	1	2	3
Annual Depth of Irrigation Applied, inches	***13.5***			
Field Size, acres	***130***			
Volume of Water Pumped, acre-inches	***1755***			
3. Propane Fuel Needed if at 100% of Performance Rating (multiply gallons per acre-inch times volume pumped)	***6984***			
4. Energy Actually Used Last Year, gallons	***8500***			
5. Energy Savings (Subtract 3 From 4), gallons	***1516***			
6. Potential Cost Savings — Cost $ / gallon	***1.70***			
Annual Cost Savings, $	***2577***			

Notes:

INVESTMENT ANALYSIS

The breakeven amount of money for improving a pumping plant is the annual savings in energy costs due to improvement multiplied times the series present worth factor.

Series Present Worth Factor

Period, years	Annual Interest Rate						
	5%	6%	7%	8%	9%	10%	12%
3	2.72	2.67	2.62	2.58	2.53	2.49	2.40
4	3.55	3.47	3.39	3.31	3.24	3.17	3.04
5	4.33	4.21	4.10	3.99	3.89	3.79	3.60
6	5.08	4.92	4.77	4.62	4.49	4.36	4.11
7	5.79	5.58	5.39	5.21	5.03	4.87	4.56
8	6.46	6.21	5.97	5.75	5.53	5.33	4.97
9	7.11	6.80	6.52	6.25	6.00	5.76	5.33
10	7.72	7.36	7.02	6.71	6.42	6.14	5.65
12	8.86	8.38	7.94	7.54	7.16	6.81	6.19
15	10.38	9.71	9.11	8.56	8.06	7.61	6.81
20	12.46	11.47	10.59	9.82	9.13	8.51	7.47
25	14.09	12.78	11.65	10.67	9.82	9.08	7.84

Breakeven Cost = Annual Savings * Series Present Worth Factor

		System			
	Example	1	2	3	4
Annual Savings, $	**2,871**				
Interest, %	**9**				
Recovery Period, years	**5**				
Series Present Worth Factor =	**3.89**				
Breakeven Improvement Cost, $	**11,168**				

Notes: