Benchmarking Performance of Irrigation Systems in Western Oklahoma

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Introduction

With the ever increasing pressure on available freshwater resources, performance improvement of irrigation systems has become critical. Irrigation is the largest consumer of global freshwater resources and the largest consumer of energy at the farm level. As such, strategies to improve performance of irrigation systems should look at both water and energy aspects especially at field level. Benchmarking is a tool that can be used to identify gaps between current and achievable/standard irrigation efficiencies to identify issues and to develop recommendations for performance improvements.

This research project was a holistic performance evaluation of center-pivot irrigation systems in western Oklahoma. The energy efficiency of irrigation pumping plants was integrated with water conveyance efficiency and irrigation application uniformity. Groundwater is one of the main sources for irrigation in western Oklahoma. Hence, significant declines in water table has occurred over the past few decades, resulting in diminished well yields and increased pumping costs. In the Oklahoma Panhandle declines of over 30 m have been reported for the Ogallala aquifer.

A total number of twenty systems were tested for energy efficiency. Eleven of these systems were also tested for water efficiency and application uniformity. Each system was unique based on the depth to water table, type and age of pump, age of irrigation system, and source of energy (electricity vs. natural gas).

Objectives

i. Estimate the Overall Pumping Efficiency (OPE) of irrigation pumping plants
ii. Estimate water conveyance efficiency and application uniformity of irrigation systems
iii. Identify issues and develop recommendations for water and energy performance improvements

Irrigation Uniformity and Efficiency

Irrigation uniformity was evaluated based on the readings from catch cans. For center pivots, the two commonly-used application uniformity indicators are **Coefficient of Uniformity (CU)** based on the recommendation of the ANSI/ASAE S436.1 standard and the **Low-Quarter Distribution Uniformity (DU_{lq}). Water conveyance efficiency (WCE)** was also estimated using the equations below.

$$CU = 1 - \frac{Average\ absolute\ deviation\ from\ mean\ weighted\ catch\ can\ readings}{Mean\ weighed\ catch\ can\ readings}$$

$$DU_{lq} = \frac{Average\ of\ the\ lowest\ quarter\ of\ weighted\ catch\ can\ readings}{Mean\ weighted\ catch\ can\ readings}$$

$$WCE = \frac{Volume\ of\ water\ that\ reached\ soil\ surface}{Volume\ of\ water\ discharged\ at\ pump\ outlet}$$

Overall Pumping Efficiency (OPE)

The OPE of a pumping plant is the relationship between the power consumed and the amount of water delivered in gallons per minute at a given pumping head, and is expressed using the horsepower equation.

$$\textbf{Overall Pumping Efficiency} = \frac{Water\ flow \times total\ dynamic\ head}{3960 \times required\ input\ horsepower} \times 100\%$$

$$\textbf{Total Dynamic Head} = pumping\ lift + discharge\ pressure \times 2.31$$

All **Electric systems** were powered by 3 phase power supply. Input power in kilowatts was estimated using the average of voltage and current of each leg and converted to horsepower as follows:

$$\textbf{Input hp} = KW \times 1.34$$

For **Internal Combustion Engine** systems, fuel consumption of known energy per unit was measured in cubic feet and converted to horsepower using the following conversion:

$$\textbf{Input hp} = fuel\ consumption \times \frac{Fuel\ Heat\ Value}{2545}$$

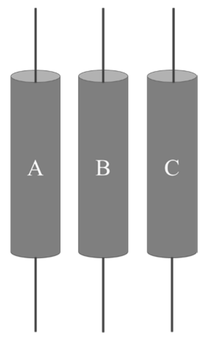
Field Measurements

Ultrasonic flow meter: Measures water flow

Water depth sounder and other tools: The black spool is the water depth sounder used to measure static pumping depth.

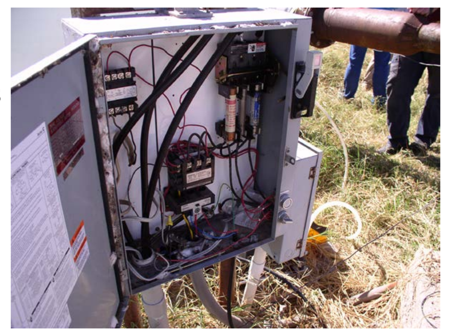
Natural gas meter: Measures the flow rate of the gas into the engine

Electric power measurement



3-Phase fuse setup: Each leg voltage and amps is averaged.

- A to B
- A to C
- B to C



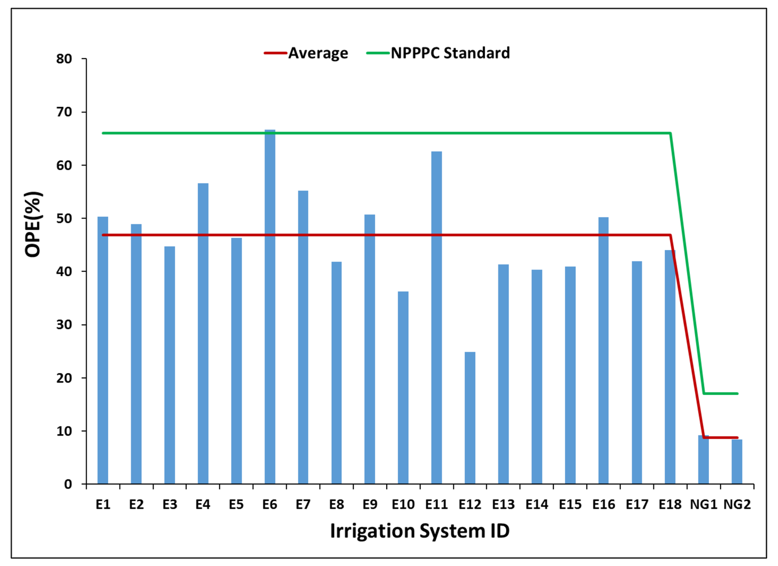
Results: OPE & Potential Cost Savings

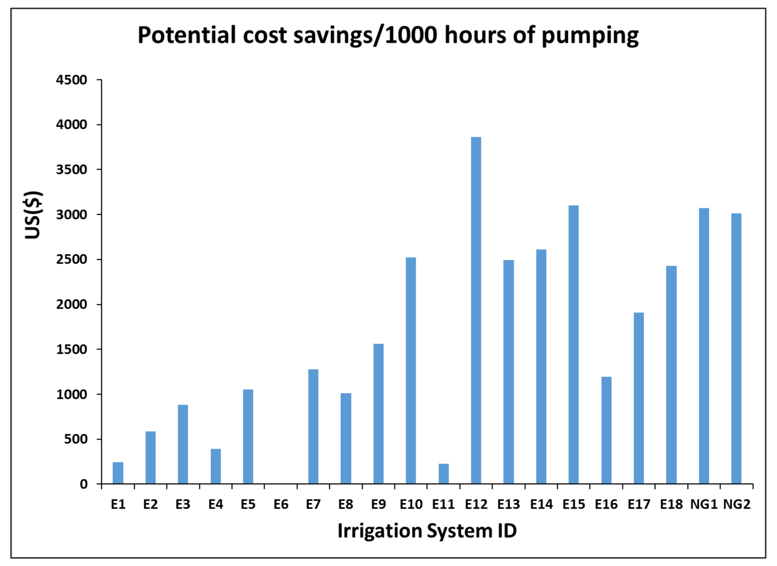
The OPE for irrigation pumping plants was benchmarked using the Nebraska Pumping Plant Performance Criteria (NPPPC) and the standard developed by the Center for Irrigation Technology (CIT) at California State University-Fresno. The NPPPC is based on the assumption that the pump efficiency is 75% and the efficiency of 88% and 24% for an electric motor and internal combustion engine respectively as highlighted in the tables below.

NPPPC		
Type	Power unit efficiency (%)	Overall Pumping Efficiency (%)
Electric	88	66
Diesel	33	24
Natural Gas	24	17

CIT		
Type	Overall Pumping Efficiency (%)	Rating
Electric	69 and above	Excellent
	63-68.9	Good
	56-62.9	Fair
	55.9 or less	Low

Of the twenty irrigation pumping plants tested, eighteen were electric powered and two were natural gas powered systems. One pumping plant out of the twenty systems had an OPE above the NPPPC. Basing on the CIT standard, there was only one "Good", two "Fair" and the other seventeen irrigation plants had "Poor" performance.





- Out of the twenty pumping plants tested, one (1) system had OPE greater than the NPPPC standard and the other nineteen (19) had OPE below the standard.
- Using the CIT performance standard, one (1) pumping plant was rated as "Good", two (2) as "Fair" and the other seventeen (17) as "Low".
- The estimated average potential cost savings for 1000 hours of pumping at the NPPPC standard was US$1,609 and US$3,044 for electric and natural gas systems respectively.
- Estimated power consumption for all types of irrigation pumps was generally high as compared to the calculated horsepower.
- The performance of natural gas systems diminished with age of the internal combustion engines as they tend to consume more fuel to pump a gallon of water.
- From the above figures, it can be seen that cost of irrigation pumping is significantly reduced when using efficient pumping plants as shown by system E6 and E11.
- The results also showed that cost saving is more pronounced when improvements are done for natural gas systems as compared to electric systems.
- The difference between the average OPE of the pumping plants tested and the NPPPC standard suggests that there is opportunity for performance improvement of pumping plants in the study area.

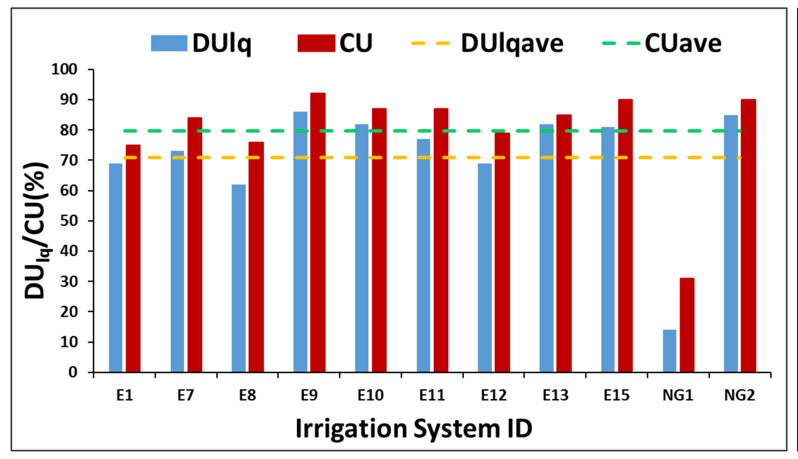
Results (continued): DU_{lq}/CU and WCE

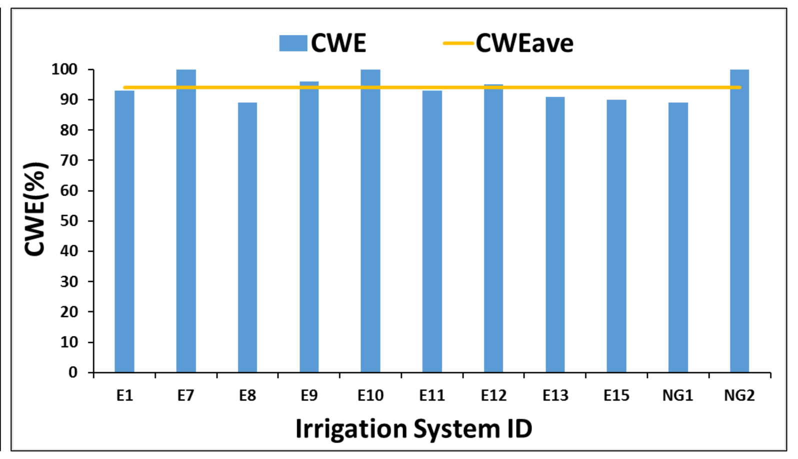
Water application uniformity is a measure of the evenness of water discharge from the nozzles. The following tables present results of the numbers of irrigation systems in widely used standard thresholds for DU_{lq} and CU .

DU_{lq} Rating		
DU_{lq} Range	Classification	Number of systems
>85%	Excellent	1
80%	Very Good	4
75%	Good	1
70%	Fair	1
<65%	Poor and unacceptable	4

CU Rating		
CU Range	Classification	Number of systems
90%-95%	Excellent	3
85%-90%	Good	3
80%-85%	Fair	1
<80%	Poor	4

The number of systems that had "Poor" application uniformity was very significant. Both benchmarks had similarities on classifying water application uniformity as highlighted by the number of systems below the "Good" category.

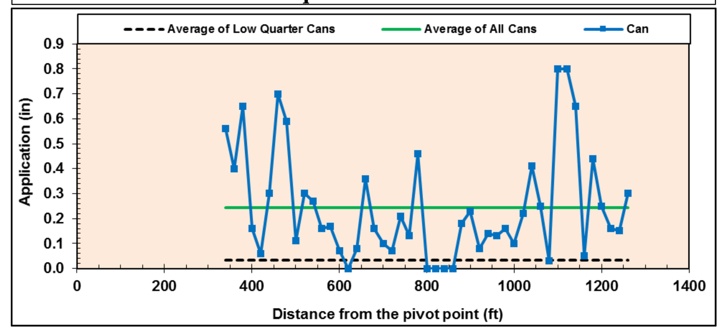




For center pivot systems, WCE is generally expected to be 100% and this occurs if there are no losses during conveyance. Even though the proportion of water loss for most systems was less than 10%, the volume of water loss could be significant if all the pivot systems in the study area are considered. Most of the losses that occurred before reaching the soil surface were due to pipe leakages. Minimizing leakages in this case will not only result in supplying more water to the field, but will also result in potential reductions in energy costs since less hours of pumping would be required to pump the same amount of water.

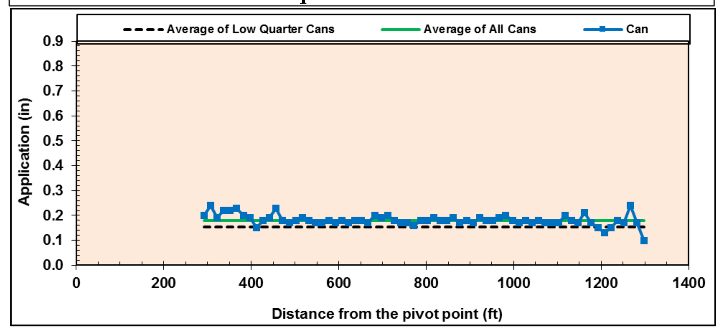
Poor uniformity

System: NG1; Pivot radius: 1260 ft
CU: 31% DU_{lq}: 14% WCE: 89%



Excellent uniformity

System: E10; Pivot radius: 1300 ft
CU: 92% DU_{lq}: 86% WCE: 96%



Conclusion

- The majority of the irrigation pumping plants had OPE below the NPPPC benchmarks
- Possible causes of low OPE included impeller misalignment, aging and changes in operating conditions
- Improving OPE of irrigation pumping plants can reduce pumping costs significantly
- The number of systems with poor water application uniformity was significant

Recommendations for Improving Systems:

- Impeller adjustments
- Lowering Pressure
- Maintenance/replacement of sprinkler nozzles
- Addressing pipe leakages

Future Work:

- Life Cycle Assessment
- Pump performance monitoring
- Impacts of performance of irrigation systems on crop water productivity

References

- ANSI/ASAE S436.1, 2007, *Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray or Sprinkler Nozzles*
- Fipps, Guy and Byron, Neal 1995, *Texas Irrigation Pumping Plant Efficiency Testing Program*
- Kenny, Nicholas 2013, *pub. 3241F Basics of On-site Pumping Plant Evaluations*
- USDA 2012, *Fact Sheet 4- Calculating Pumping Efficiency & Performance*

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