AN INTEGRATED EVALUATION TO IMPROVE CENTER PIVOT ENERGY AND WATER USE

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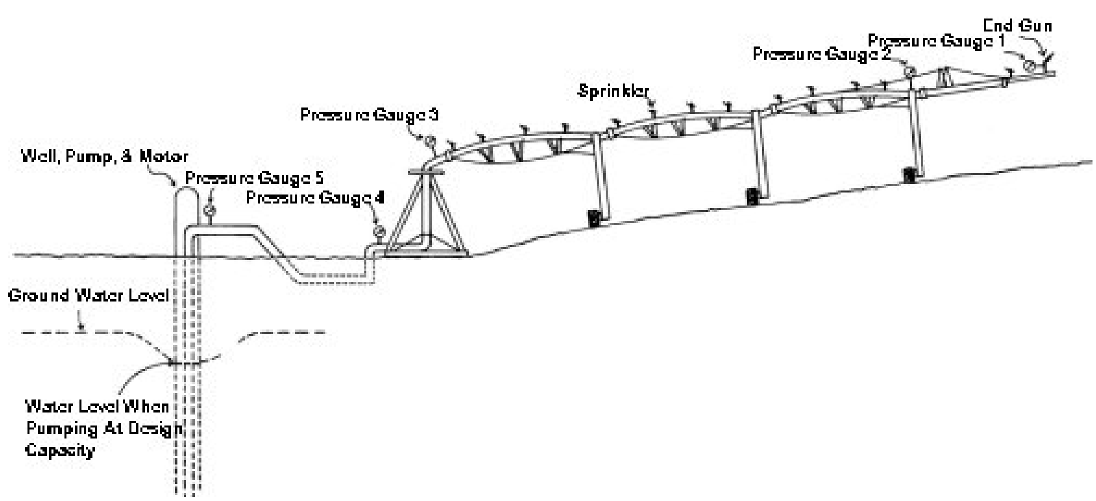
An Irrigation System consists of four important components that are inter-related. They are;

1) Well
2) Pumping Plant
3) Irrigation System

A fourth constraint would be the field's water rights. In Kansas a water right consists of a place of use (acres) or footprint that the water can be applied to, a maximum allowed flow rate (gpm), and Allotment or volume of water that is allowed to be pumped in a season (Acre-Ft)

Good design and operation must consider all three components to meet the crop water needs with the most efficient energy and resource management and stay within the parameters of the water right.

This Integrated Evaluation approach is based on 10 years of field testing for the NRCS Conservation Stewardship Program's WQT-03 Pumping Plant Evaluation. Their test is a starting point. If it was also the end point then important inter-relationships would be missed. For example if the pumping plant is found to have a high efficiency but is not supplying the correct pressure and flow rate as required by the pivot package design then there is a misfit. If it is pumping more than the well's sustainable yield then another misfit is occurring.



Schematic of Irrigation System Components

Well Performance

The well is a hydraulic structure that intercepts the groundwater aquifer to provide the irrigation system designed flow rate or Irrigation System Capacity, defined as the flow rate-gpm/acre. This ratio multiplied by 0.05 gives the inches applied per each acre in a 24 hour operation. This can be compared to Crop ET.
The well performance characteristic is the Specific Capacity, measured in gpm/drawdown. Drawdown is the difference between Static and Pumping water levels.

< 5	Poor
5-10	Fair
10-20	OK
20-50	Good
>50	Excellent

Compare this to your well drillers report when the well was constructed if they did a well performance test.

Also important is to evaluate if the well has additional flow rate (especially if difficulty meeting crop water needs), or if it is being over-pumped. Pumping water level should not be very far below the top of the well screen nor too close to the bottom of the well. The Driller's well log will provide these criteria. If the operating pressure of the irrigation system is fluctuating or pumping a lot of air this is an indication that the well is being pumped for more water than it can sustain.

Current Static water level should be compared to the new well's static water level to see how much the groundwater conditions have changed.

A description of the NRCS test is found below.

Pumping Plant Performance

The Nebraska Pumping Plant Performance Criteria, NPPPC provides an accurate assessment of how good the conversion of energy is from electricity, natural gas or diesel. Using your actual energy used for a given volume of water pumped (acre-inches) to what the NPPPC estimates should be your energy consumption, is a helpful comparison to determine whether improvements should be considered. This NPPPC portion of the evaluation assumes a pump efficiency (WHP/BHP) of 75% and an electric motor efficiency (BHP/MHP) of 88% for an overall efficiency of 66%.

Water Horsepower, WHP, is the useful work done by the pumping plant and should meet the design requirements of the irrigation system. It is the product of the flow rate being pumped, and the TDH, total dynamic head, or pressure developed at the pump location in the well at the bottom of the column pipe. The TDH is the sum of the pumping water level, pressure at the discharge and minor losses.

Brake Horsepower, BHP, is the pump's rotational shaft power that is demanded by the pump impellers at a specific rpm. Motor Horsepower, MHP, is the input energy measured by the electric company's power meter if an electric motor or the hourly consumption of natural gas or diesel if an engine.

United States Department of Agriculture
Natural Resources Conservation Service

Water Quantity Enhancement Activity – WQT03 - Irrigation Pumping Plant Evaluation

Irrigation Pumping Plant Evaluation
This enhancement consists of the evaluation of the pumping plant performance and efficiency using the Nebraska Irrigation Pumping Plant Performance Criteria.

Land Use Applicability

This enhancement is applicable on cropland and pastureland

Benefits
A pumping plant performance test can determine the energy efficiency of an irrigation pumping plant and provide information on adjustments or modifications needed to improve the energy efficiency. Efficiency improvements come in the form of reduced energy consumption, reduced water use and better management techniques. A pumping plant test may be performed regardless of the age of the system.

Criteria for Irrigation Pumping Plant Evaluation

An irrigation pumping plant performance test must be performed by a trained service provider with appropriate testing equipment. A full and complete report must be completed by the service provider. This should include:

- Age and condition of the components of the irrigation system and pumping plant
- Water levels during pumping, a pressure / discharge curve
- Pump and engine speed (rpm)
- Actual Pump Plant Performance versus the Nebraska Performance Criteria
- Actual pump efficiency versus the Manufacturers Published efficiency
- Recommendations for improvements to the overall system efficiency
- Estimate of energy savings if improvements are implemented

Nebraska Performance Standards for Irrigation Pumping Plants [8]

Energy Source	Energy Unit	Hp-hr[1] Per Unit of Energy	Water Hp-hr[2] Per Unit of Energy[3]
Diesel	Gallon	16.7	12.5
Gasoline	Gallon	11.5 [4]	8.66
Propane	Gallon	9.2 [4]	6.89
Natural Gas	1,000 cu ft	88.9[5]	66.7
Electricity	kWh	1.18[6]	0.885[7]

A sprinkler package is designed for a specific Flow Rate-gpm and Pressure-psi at the top of the pivot riser. The Pumping plant must be able to provide this minimum pressure and the well must be able to sustain the flow rate.

If the pressure is not sufficient expect uniformity of application problems, especially in the higher elevations of the center pivot system. Not applying the same amount of water in all parts of the field is not a good situation. Low pressure operation of center pivots is a common occurrence. With today's technology consider monitoring the end tower pressure as it makes a revolution.

Most pivot packages use pressure regulators to provide uniform pressure to the individual sprinkler's nozzle, especially important if the field has more than 5 ft. of elevation difference. Manufacturers require that the minimum input pressure for the regulator is 5 psi more than the rated psi setting. Often there is sufficient pressure for the regulators at the pivot, but not at the end of the system that irrigates a significant area of the field. This is due to elevation rises from the pivot and friction loss down the pivot lateral (5-15 psi). One psi is equal to 2.3 ft. of elevation. Pressure measured at the base of the pivot will always be 5-6 psi less than the top of the pivot.

A sample evaluation will help understand the details. It is a typical center pivot in central Kansas with a new well on the north side of the field and a new electrical pumping plant. It has a new pivot sprinkler package of R-3000 Rotators with an orange pad, 20 psi regulators designed for 800 gpm at 33 psi on top of the pivot. The drop height is 7-8 ft. Spacing of drops are every other outlet from Pivot to Tower 4, then every outlet (9-10 ft.). There is no end gun. The well and pump are located about 1300 ft. north of the pivot. Underground mainline is 8"-80 psi PVC PIP. There is roughly a 34 ft. elevation difference between the highest and lowest end tower track. The Pivot has an AgSense with pressure transducer.

Water Duty or Water Use Efficiency

Water Duty can be defined as the yield (Bushels/acre for corn / inch of irrigation applied.

This field averaged just under 200 bushels/acre and had an average 15 inches or irrigation, resulting in a Water Duty of 13.3.

A PDF of the yield in 2019 is as follows. Notice the difference in yield between the NW and SE quadrants. Something is going on to reduce yield, 30-40 B/acre from its potential.

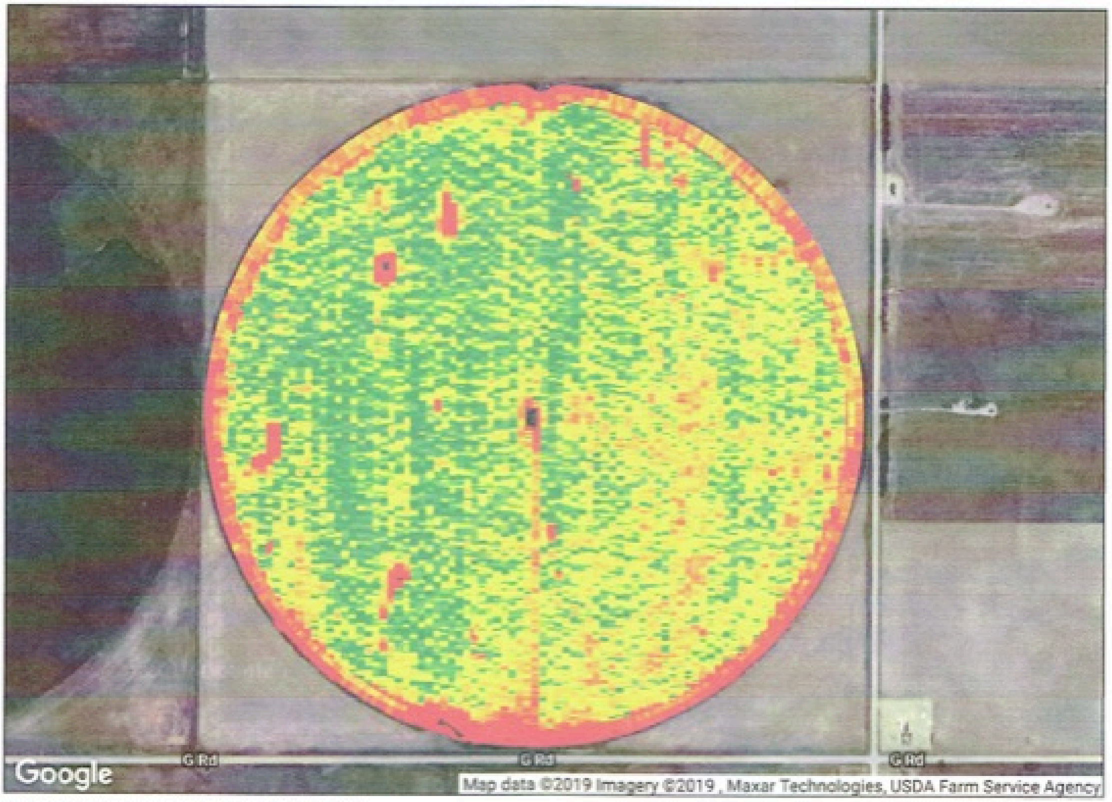
JOHN DEERE

Operations Center

2019 Corn: Harvest

[redacted]

Layer: Dry Yield



Operation Dates: 09/13/2019 - 09/15/2019

AGRONOMIC DATA

TOTAL DRY YIELD 24,832.36 bu	**AVG. WET WEIGHT** 13,109.57 lb/ac
AVG. DRY YIELD 198.67 bu/ac	
AVG. MSTR 27.79 %	
AVG. SPEED 3.17 mi/h	
AREA WORKED 124.99 ac	
WET WEIGHT 1,638,565.11 lb	

Pressures on Aug 3rd Irrigation
At End Tower

Angle	PSI	G.E. Elevations
0	13.1	2048
91	15.9	2030
180	12.1	2050
230	9.6	2058
323	9.7	2060

LEGEND

235	11 %
221	23 %
209	24 %
194	19 %
174	10 %
146	5 %
0	8 %

Kansas Farms			
Pump/Well/System Testing		Improving Pump to new efficiency status	
		Correcting Low Pressure problem	Nov-19
	Nov-19		#75
	#75		
Flow Rate timed McCrometer	769	Flow Rate	700
Collins Meter Gpm		Press at end tower	25
Needle reading McCrometer	760	HF pivot friction loss psi	7.43
Pressure at pump	35	Psi loss to highest pt in field	3.46
Pressure at pivot base	30	Measured PSI loss to pivot base	5
Press on top of pivot	24	(adjusted to design flow rate	
Nozzling Package Design GPM	800	Required Press at Pump	46.09
PSI on top of pivot	33	Required Press at Pivot on Top	35.89
Pressure REG setting	20		
Estimated Pressure at End Tower	R-3000 Orange	Design Total Dynamic Head, TDH	214.51
In highest elevation of field -psi	13.11	Includes 5 future GW decline	
Required Pressure Minimum	25	Water HP	37.92
	Low	Pumping Water Level Future	101
Static Water Level	66		
Pumping Water Level	99	Mainline to Pivot Hydraulics Pipe ID	7.8
Well's Specific Capacity		Length ft	1300
gpm/ft of DD	23.30	Hf friction loss psi	4.69
Total Dynamic Head	189.85	Cost per kWh	$0.12
Water HP	36.87	Energy Use Comparison	
		AS IS kWh	70,601
Nameplate HP	60	Energy Cost AS IS	$8,472
Rated Amps/Volts	74.5/460	OP Hours at Design Flow Rate	1,514
Tested Amps	71,70,71	New Pump Water HP	37.92
Tested Volts	490	Brake HP 82% pump efficiency	46.24
Midwest Meter #	500000637	Motor Size	50
Kh	1.2	Pump KWDemand	39.20
Time to complete 10 rev - sec	62.3		
Meter MHP	74.27		
Meter Multiplier	80.00	Total kWhours	59,361
Equation MHP	68.66	Cost of kWh	$0.12
Overall PUMP Plant Efficiency	53.70%	Total Electrical Annual Cost	$7,123
NPPPC standard	65%	Savings in Energy Cost	$1,349
% of NPPPC standard	83%		
Pump KWDemand	51.22		
		Combined BTU As Is	240,960,164
Permit number	34918	Combined BTU Future	202,598,785
Alloted Acres	160	Savings in BTU per year	38,361,379
Maximum Flow rate	755	% Energy Savings	15.92%
Alloted AF	195		
Actual acres irrigated	120		
WELL Depth WWC5 KGS	214		
SWL WWC5	54(2018)		
Operating Hours Calculations			
Max Inches applied per acre	19.50		
OP Hours in a drier year	1,378		
Elevation at Pivot	2053		
Elevation at Well	2048		
Elevation at Highest pt in field	2061		
Lowest pt	2027		

Details make a difference.   An explanation of the measured data and analysis going down the spreadsheet column of the test conditions is as follows.

Flow Rate – gpm. Both the McCrometer needle reading and 10 minute volumetric test are displayed to make sure the needle reading is accurate.   This flow rate should be compared to the Design Package flow and pressure.   In this case the flow rate is down 40 gpm due to low pressures. The orientation of the pivot during the test was to the south alongside the pivot access road.

Pressures at the pump, base of pivot, and calculated top of pivot are provided.   Each 2.3 ft. in elevation is 1 psi.   Therefore base of pivot pressure should be 6 psi more than the top of pivot.   It is important to note that the top of pivot pressure is what the Design is based on.   In our case 33 psi is required by the design, yet there is only 24 psi on top of pivot, thus we expect low pressure caused uniformity problems.

Following is the AgSense graph for an early august irrigation showing the location (angle) and end tower pressure.   For 20 psi regulators 25 psi is required at the end tower. It never reached that even in low elevation area of field to the SE.

WATER WELL RECORD Form WWC-5

☒ Original Record ☐ Correction ☐ Change in Well Use

Division of Water Resources App. No. 34,918 Well ID

1 LOCATION OF WATER WELL: County: Pawnee | Fraction ¼ NE ¼ NW ¼ SE ¼ | Section Number 34 | Township Number T 22 S | Range Number R 16 ☐ E ☒ W

2 WELL OWNER: Last Name: First:
Business: ILS Land LLC
Address: P O Box 1506
Address:
City: Great Bend State: KS ZIP: 67530

Street or Rural Address where well is located (if unknown, distance and direction from nearest town or intersection): If at owner's address, check here: ☐
2 1/2 North, 1 1/4 East of Zook

3 LOCATE WELL WITH "X" IN SECTION BOX: N, NW, NE, W, E, SW, SE (X), S, 1 mile

4 DEPTH OF COMPLETED WELL: 214 ft.
Depth(s) Groundwater Encountered: 1) .... ft. 2) .... ft. 3) .... ft., or 4) ☐ Dry Well
WELL'S STATIC WATER LEVEL: 54 ft.
☒ below land surface, measured on (mo-day-yr) 3-23-18
☐ above land surface, measured on (mo-day-yr)........
Pump test data: Well water was .... ft. after........ hours pumping .... gpm
Well water was .... ft. after........ hours pumping .... gpm
Estimated Yield: .... gpm
Bore Hole Diameter: 30 in. to 214 ft. and .... in. to .... ft.

5 Latitude: .... (decimal degrees)
Longitude: .... (decimal degrees)
Horizontal Datum: ☐ WGS 84 ☐ NAD 83 ☐ NAD 27
Source for Latitude/Longitude:
☐ GPS (unit make/model: ....) (WAAS enabled? ☐ Yes ☐ No)
☐ Land Survey ☐ Topographic Map
☐ Online Mapper: ....

6 Elevation: .... ft. ☐ Ground Level ☐ TOC
Source: ☐ Land Survey ☐ GPS ☐ Topographic Map ☐ Other ....

7 WELL WATER TO BE USED AS:
1. Domestic: ☐ Household ☐ Lawn & Garden ☐ Livestock
2. ☒ Irrigation
3. ☐ Feedlot
4. ☐ Industrial
5. ☐ Public Water Supply: well ID ....
6. ☐ Dewatering: how many wells? ....
7. ☐ Aquifer Recharge: well ID ....
8. ☐ Monitoring: well ID ....
9. Environmental Remediation: well ID .... ☐ Air Sparge ☐ Soil Vapor Extraction ☐ Recovery ☐ Injection
10. ☐ Oil Field Water Supply: lease ....
11. Test Hole: well ID .... ☐ Cased ☐ Uncased ☐ Geotechnical
12. Geothermal: how many bores? .... a) Closed Loop ☐ Horizontal ☐ Vertical b) Open Loop ☐ Surface Discharge ☐ Inj. of Water
13. ☐ Other (specify): ....

Was a chemical/bacteriological sample submitted to KDHE? ☐ Yes ☒ No If yes, date sample was submitted: ....
Water well disinfected? ☒ Yes ☐ No

8 TYPE OF CASING USED: ☐ Steel ☒ PVC ☐ Other .... CASING JOINTS: ☒ Glued ☐ Clamped ☐ Welded ☐ Threaded
Casing diameter 16 in. to 214 ft., Diameter .... in. to .... ft., Diameter .... in. to .... ft.
Casing height above land surface 18 in. Weight Sch.40 lbs./ft. Wall thickness or gauge No. ....

TYPE OF SCREEN OR PERFORATION MATERIAL:
☐ Steel ☒ Stainless Steel ☐ Fiberglass ☐ PVC ☐ Other (Specify) ....
☐ Brass ☐ Galvanized Steel ☐ Concrete tile ☐ None used (open hole)

SCREEN OR PERFORATION OPENINGS ARE:
☐ Continuous Slot ☐ Mill Slot ☐ Gauze Wrapped ☐ Torch Cut ☐ Drilled Holes ☐ Other (Specify) ....
☐ Louvered Shutter ☐ Key Punched ☐ Wire Wrapped ☒ Saw Cut ☐ None (Open Hole)

SCREEN-PERFORATED INTERVALS: From 214 ft. to 174 ft., From .... ft. to .... ft., From .... ft. to .... ft.
GRAVEL PACK INTERVALS: From 214 ft. to 20 ft., From .... ft. to .... ft., From .... ft. to .... ft.

9 GROUT MATERIAL: ☐ Neat cement ☐ Cement grout ☒ Bentonite ☐ Other ....
Grout Intervals: From .... ft. to .... ft., From 20 ft. to 0 ft., From .... ft. to .... ft.

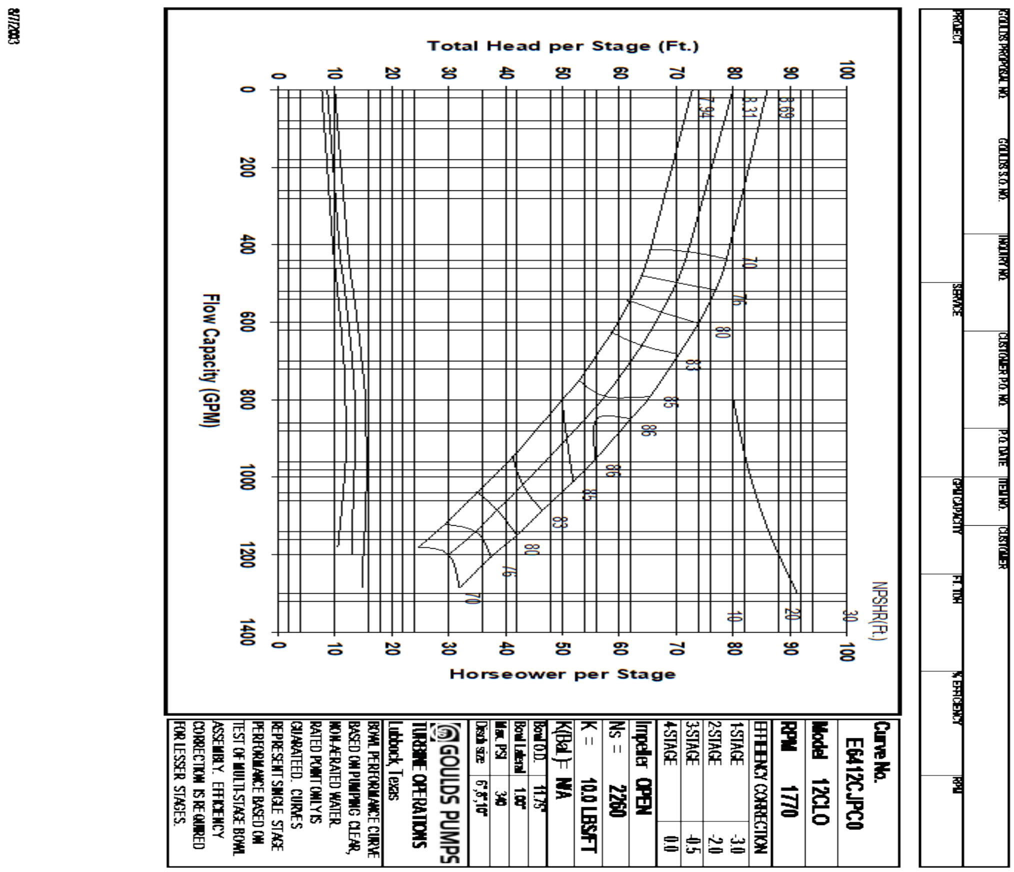
Nearest source of possible contamination:
☐ Septic Tank ☐ Sewer Lines ☐ Watertight Sewer Lines ☒ Other (Specify) None
☐ Lateral Lines ☐ Cess Pool ☐ Seepage Pit
☐ Pit Privy ☐ Sewage Lagoon ☐ Feedyard
☐ Livestock Pens ☐ Fuel Storage ☐ Fertilizer Storage
☐ Insecticide Storage ☐ Abandoned Water Well ☐ Oil Well/Gas Well
Direction from well? .... Distance from well? .... ft.

10 FROM	TO	LITHOLOGIC LOG	FROM	TO	LITHO. LOG (cont.) or PLUGGING INTERVALS
0	2	Top soil	152	155	Cemented sand streaks
2	10	Brown clay	155	165	Green gray clay
10	52	Soft sandy clay	165	180	Gravel- fine to small clean
52	62	Soft cemented sand	180	184	Tan clay
62	85	Sand & gravel- small med clean coarse	184	214	Sand & gravel- med clean coarse
		loose			w/ broken rock (ironated)
85	89	Green gray tinted clay	**Notes:**		
89	110	Tan clay			
110	152	Green gray tan clay			

11 CONTRACTOR'S OR LANDOWNER'S CERTIFICATION: This water well was ☒ constructed, ☐ reconstructed, or ☐ plugged under my jurisdiction and was completed on (mo-day-year) 4-6-18 and this record is true to the best of my knowledge and belief. Kansas Water Well Contractor's License No. 134. This Water Well Record was completed on (mo-day-year) 4-24-18 under the business name of Rosencrantz-Bemis Ent Inc Signature [signature]

Mail 1 white copy along with a fee of $5.00 for each constructed well to: Kansas Department of Health and Environment, Bureau of Water, GWTS Section, 1000 SW Jackson St., Suite 420, Topeka, Kansas 66612-1367. Mail one to Water Well Owner and retain one for your records. Telephone 785-296-5524.
Visit us at http://www.kdheks.gov/waterwell/index.html KSA 82a-1212 Revised 7/10/2015

Well log from 2018. Test pumped at 1000 gpm at 118 ft. pumping water level. Checked in August 2018 at 830 gpm and 159 ft. pumping and only 32 psi at pump discharge. Check where the screens are located and how this relates to the tested pumping water level.



The pump is a new Goulds 4-stage, 8.44” diameter, a B+ trim, installed in 2018. Designed for 800 gpm with TDH = 252 ft. and 58 Brake HP demand.

It was tested at 190 ft. TDH at 769 gpm. The curve predicts a TDH of 268 ft. (67 ft/stage), so there is quite a variance. The curve also predicts a Brake HP of 56 total (14 BHP/stage). According to the test of the motor it is pulling just under (71, 70, 71) the full load amps, FLA on the nameplate of 74.5.

The overall efficiency is calculated at 53%, not very good compared to the Nebraska Standard of 66%.

End tower pressure is estimated for the worst case of lowest pressure to make sure there is still sufficient pressure for even irrigation, wherever the pivot is located. Using Google Earth the elevations around the end tower track is noted and compared to the pivot elevation to obtain the largest uphill difference.

Well performance is determined from the Specific Capacity (gpm/ft. of drawdown (Pumping-Static)). This can be compared to the historical performance tested when the well was drilled or more recent pumping plant evaluations.

There are two methods to determine the Motor HP. The electrical service meter can often be used to measure the flow rate of electrical energy to the motor. The meter face gives the meter characteristics of Kh and if lucky you can measure the time in seconds to complete 10 wheel revolutions. If the meter is not measuring the full energy then there is a multiplier that must be used. Often the Meter Kilowatt Demand is also listed as the meter monitor rotates through the different screens.

Meter MHP = 10 revolutions * Kh*4.82 / seconds for 10 revolutions.

A second estimate is the following based on the 3 phase amps and voltage tested at the motor panel. Remember that the Meter is measuring all energy being delivered such as tower motors and end gun booster pumps. For just the pump MHP these minor motors should be subtracted.

Equation MHP = average amps * average volts * (3)^0.5 * Power Factor (0.85 estimate) / 746

The overall efficiency can now be calculated as the ratio of WHP/MHP.

It is also good to check the 3 phase line amperages for overload and imbalance. If there is more than 7-10% difference in the amperages there would be concern for motor life.

Water rights are summarized for the particular well as a reference point and to make sure flow rates are within the permit allowance.

To estimate energy costs per year it is necessary to calculate the total operating hours to apply the allocation. The operating hours are determined at the tested flow rate and the pivot's irrigated acreage. It assumes full use of the water right in a hot dry summer.

Future Projections

The second column on the analysis spreadsheet is a prediction of any changes (flow rates, sprinkler package design) or improvements (bringing up overall efficiency to Nebraska Standard) and what the impact on energy consumption would be compared to the AS IS conditions tested. An adjustment should be made in this case as the AS IS was not at sufficient pressure.

This would improve the annual potential savings by increasing the AS IS conditions to have sufficient pressure as a new design would have to have, a level playing field. Notice on the test that the end tower pressure was estimated to be 12 psi low in the highest elevation of the field. This would add 28 ft. to the TDH tested or 15% more energy consumption. So the AS IS energy cost would increase from $8,472 to $9,743, resulting in an annual savings of $2,613.

The final 4 lines are for possible REAP-EEI grant application from the USDA Rural Development agency. The adjusted energy savings would be 27% and 74,500,000 BTU.