IMPACT OF VARIABLE WELL YIELD ON CENTER PIVOT PACKAGES

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INTRODUCTION

Irrigation in the Central Plains began in the 1930's and 1940's when farmers began drilling wells. The 1960's saw rapid irrigation development, as the center pivots became a proven technology. The growth has been quite slow since the 1980's when the drilling of wells has been controlled. There is a continual increase in drawdown of the water table in many areas of the Central Plains.

McGuire, 2004 published a Fact Sheet presenting the water-level changes in the High Plains Aquifer. Two periods were highlighted, predevelopment to 2003 and 2002 to 2003. McGuire reported that in 1949 there was 2.1 million irrigated acres compared to 13.7 million acres in 1980. The irrigated area peaked at 13.9 million acres in 1997 and reduced to 12.7 million acres in 2002. Ground water withdrawals increased from 4 to 19 million acre-feet from 1949 to 1974. The withdrawals exceed the recharge and the pumping lifts are continuing to increase. The objective of this paper is to discuss the effect the continuing decrease on water levels have on center pivot irrigation systems. Area weighted average water level changes are -1.0, -1.7, and -1.3 feet in the states of Colorado, Kansas and Nebraska. The 2002-2003 water level changes varied from a rise of 9 feet to a decline of 14 feet. There were significant areas that had ground water declines in excess of 5 feet in a one-year period. Southwest Kansas had areas of greater than 50 feet decline in water levels from the predevelopment to 2003. Obviously, much of this occurred in the later years with the increased irrigation development. Pumping of air is a major problem that is readily observed. It is the gradual decline in the water table and the decrease in irrigation uniformity that is not as easily observed.

ANALYSIS OF INCREASED PUMPING DEPTHS

The analysis of center pivot performance is made using a computer simulation program (CPED). Presentations of the use of CPED were given at the previous two Central Plains Irrigation Conferences. The program simulates the application depths for the center pivot irrigation system. The input to the program includes the pump characteristics, the sprinkler package and lateral dimensions. The pumping level or total dynamic lift (TDL) is input to the program. The program solves the hydraulics of the center pivot system and pumping plant to determine the total discharge and pressure on the center pivot system. The problem of pumping air cannot be analyzed with the simulation analysis. It is assumed that the pump has sufficient net positive suction head to prevent air entrainment as it is lifted from the ground water and pressurized for the center pivot. The increase in TDL is assumed to be at least 10 feet and that it could easily approach 50 feet over just a few years, much less than the life of a center pivot system.

CENTER PIVOT AND PUMP SYSTEMS

Four center pivot systems are used to illustrate the characteristics of various pump and sprinkler packages. Table 1 summarizes the variables of each of the systems simulated. Assuming a change in the number of pump stages are used to illustrate their effect on the adequacy of an existing system All the systems with pressure regulators had big guns with booster pumps at the end of the lateral. Changes in the pressure and operating point on the pump curve with changes in TDL are a function of the unregulated sprinkler head until the pressure was below the regulator pressure. The analysis assumes that the sprinkler packages provide uniform irrigations when adequate pressure is maintained. The data are from systems installed in the Great Plains.

Table 1. A brief description of the systems used for illustrating the effect of changes in the total dynamic lift (TDL).

System	H	P	B	K
Towers	7	7	8	14
Length, ft.	1287	1260	1491	2584
Sprinkler type	Iwob	Impact	Rotator	Spray
No. of Sprinkler	123	42	170	206
Sprinkler spacing, ft	18/9	30	9	18/9
Pressure Regulator	Yes	No	Yes	Yes
Pump stages, no.	3/2	7/3/2	1/2	4/3
Topography, differential ft.	20	0	0	3
TDL, ft	90- 190	90- 350	20-150	78- 128

<u>System H</u>

The first system simulated is a low pressure system with inverted wobbler[1] nozzles. Pressure regulators are installed on all application devices except for

[1] Mention of reference to a particular model of brand name is not an endorsement but is only for information that may be useful to the reader.

the big gun on the end of the system. There is 20 feet of elevation change along the 1300 foot lateral. The system was installed with a three stage pump that can accommodate a 100 foot increase in TDL and still maintain sufficient pressure. This example demonstrates an over-design where one stage could be removed and still meets the demands with the existing sprinkler package. Figure 1 illustrates the elevation and pressure head distribution at each of the towers. The minimum elevation and pressure head requirements at the end of the system is approximately 213 feet which is at least 10 feet less than provided with a 190 ft. TDL.

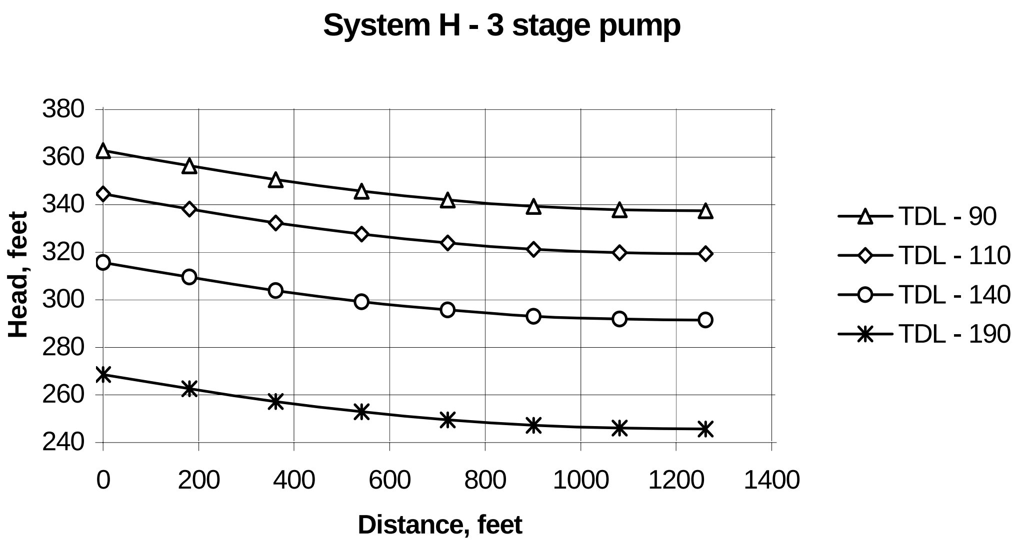

Figure 1. Lateral pressure head curves for System H (three stage pump) as installed with increases in total dynamic lift from 90 to 190 feet. Elevation and pressure head at end of system must equal 231 feet to meet minimum pressure requirements for installed sprinkler package.

Figure 2 is the same center pivot system but with one stage removed from the pump. The lower curve is the elevation of the center pivot pad and each of the towers. The difference between this and the elevation and pressure head distribution in the curves for the different TDL's, demonstrates the need for pressure regulation. The curves for the TDL of 90 and 110 meet the minimum pressure along the entire length of the system. However, with the increase in drawdown of 50 feet (TDL=140), the pressure is no longer sufficient to meet the required minimum.

Table 2 and 3 summarize the operating conditions for the three and two stage pumps, respectively. For the three stage pump the change in total discharge is a result of the big gun without pressure regulation. The reduced application depth is due to the reduced application with the big gun at the outer end of the pivot. The KW demand decreases with an increase in TDL. This is due to a lower pivot pressure and decrease in the big gun discharge. The KW demand and the head/stage is nearly the same for all conditions.

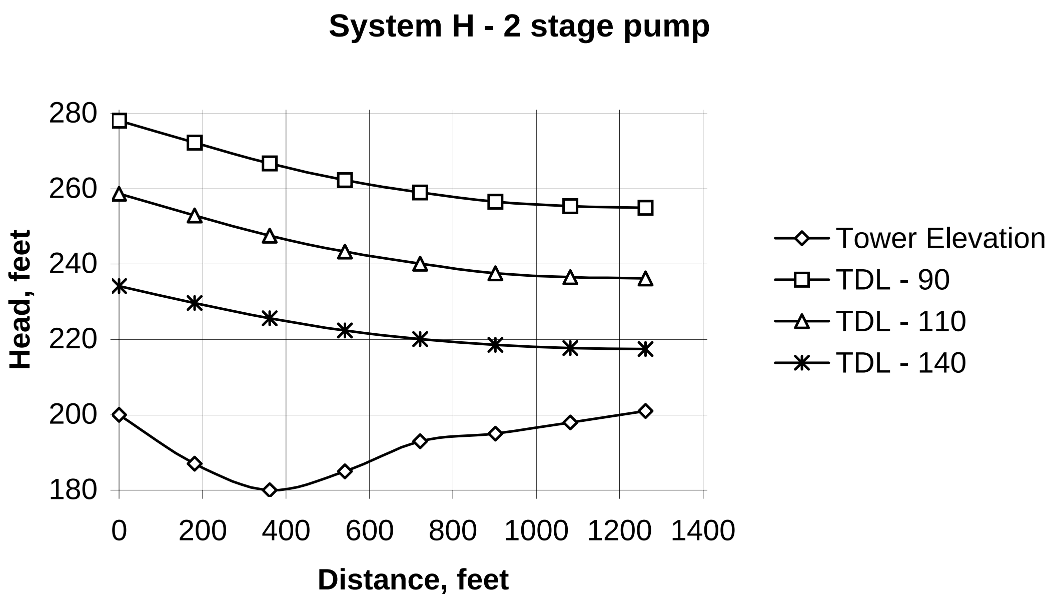

Figure 2. Lateral pressure head curves for System H (two stage pump) with increases in total dynamic lift from 90 to 140 feet. Elevation and pressure head at end of system must equal 231 feet to meet minimum pressure requirements for installed sprinkler package.

Table 2. Simulated operating characteristics for System H with three stage pump as was installed.

TDL, feet	90	110	140	190
Discharge,gpm	829	823	812	793
Pivot Pressure, psi	71	63	50	30
Irrigation depth, in.	0.77	0.77	0.76	0.75
Big gun, gpm	135	129	119	99
Head/stage, feet	88.0	88.5	88.9	89.8
KW	58.9	58.8	58.3	57.5

Table 3. Simulated operating characteristics for System H with two stage pump.

TDL, feet	90	110	140
Discharge,gpm	797	788	692
Pivot Pressure, psi	34	25	15
Irrigation depth, in.	0.75	0.74	0.66
Big gun, gpm	103	94	85
Head/stage, feet	89.6	89.8	92.2
KW	38.4	38.1	34.3

However, when one stage is removed, (Table 3) the big gun discharge is reduced as well as the application depth. A larger booster pump for the big gun could easily correct this.   The head/stage is approximately the same as for the three stage pump. The final incremental increase in drawdown of 50 feet to a TDL of 140 does result in the pressure not being met at the outer end of the lateral. The discharge decreased and the application depth decreased from 3/4 inch to 2/3 inch.

The major benefit of the two stage pump is the reduction of power requirements. Assuming a pump efficiency of 70%, the demand is reduced from 59 to 38 KW. Operating with the three stage pump will obviously provide for a larger safety factor that can accommodate a larger increase in TDL. However, the two stage pump can easily accommodate a 20 foot increase in drawdown, with the current design conditions. The irrigator can still consider a change to a three stage pump when water levels decline further

System P

System P is similar in length to System H but the sprinklers are high pressure impact heads. The system is assumed to have no topography change along the lateral. The system is simulated with three pump configurations having 7, 3, and 2 stages. It is the only system in this study that does not have pressure regulators along the lateral. The seven stage pump has TDL range from 300 to 350 feet. The TDL range for the two and three stage pumps is 90 to 100 feet.

Figure 3 illustrates the pump curves for the 3, 4, and 7 stage pumps. The system operating points for the simulation are plotted on the pump curves. The discharge range for all simulations is between 600 to 800 gpm. The system without pressure regulators does exhibit a drop in the irrigation depth even with an increase in TDL by 10 feet (Table 4, 5). The Christiansen uniformity for each of the different pump configurations is 89 to 90%. An increase of 10 feet in the TDL for the four stage pump had a 0.02 in. decrease in application depth with a decrease in CU from 90 to 80%. The decrease in uniformity is primarily caused by the change in discharge and the pattern radius of the big gun. Comparing the three stage pump with TDL=90 and the seven stage pump with TDL=350 illustrates this fact. The pivot pressures are only 2% different but the CU is 11% different. Examining the depth data shows that the big gun has a major influence on the CU. CPEDlite used by the NRCS for EQIP funding does not include the big gun in the uniformity calculations. It is included here only to see the effect of changing TDL on the system performance. The take home message is that the increase in TDL can decrease the application depth by 10 – 15%.

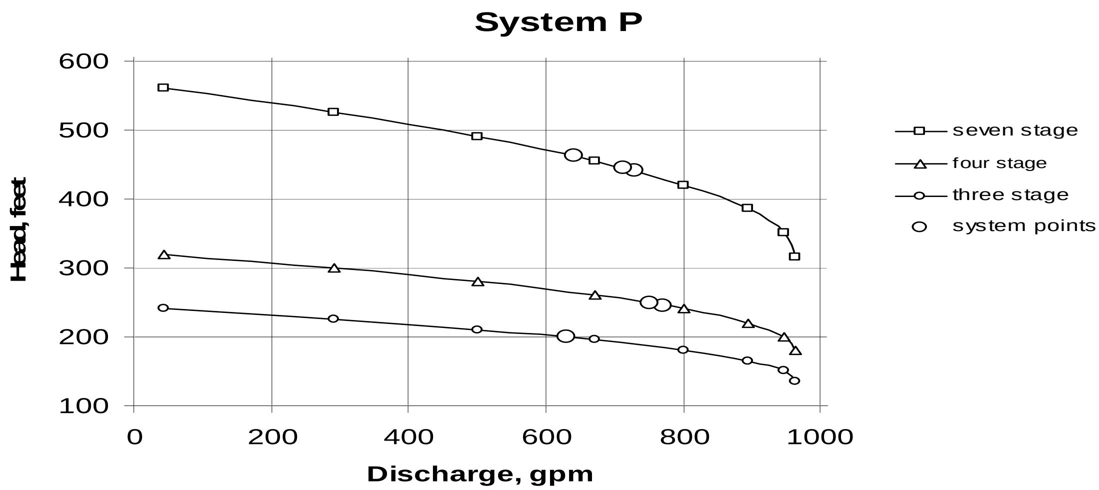

Figure 3. The pump curves for the different number of stages for System P. The operating points are for the one included in the simulation analysis of this system.

Table 4. Simulated operating characteristics for System P with seven stage pump as was installed.

TDL, feet	300	310	350
Discharge,gpm	729	712	642
Pivot Pressure, psi	55	53	43
Irrigation depth, in.	0.77	0.75	0.68
Big gun, gpm	32	31	28
Head/stage, feet	63	63.6	66.1
KW	86.5	85.3	79.9
CU	89	89	78

Table 5. Simulated operating characteristics for System P with three and four stage pump to illustrate the lower power requirement.

Pump stages	3	4	4
TDL, feet	90	90	100
Discharge,gpm	630	769	751
Pivot Pressure, psi	41	61	59
Irrigation depth, in.	0.67	0.81	0.79
Big gun, gpm	27	33	33
Head/stage, feet	66.3	61.4	62.3
KW	33.7	50.8	50.4
CU	89	90	80

System B

System B is a pressure regulated system with a rotator sprinkler package. Both a single and double stage pump are used in the simulations. The system is also assumed to be operating on a level field. Figure 4 shows the pump curves and simulated operating points for the single and double stage pumps. Again the two pump curves are used to illustrate the effect of TDL changes over different ranges. The one and two pumps used a TDL range from 0-50 feet and 90-150 feet, respectively (Table 6). The one stage pump with TDL=0 feet and the two stage pump with TDL=90 are equivalent for the center pivot system. The pivot pressures vary only by 1 psi. In each case the head/stage is equal to 86.7 feet, thus the pressure difference is the difference between the TDL and the head/stage. The simulations demonstrate that a delta change in TDL has the same effect on the center pivot pressures whether the TDL is small or much larger. The increased TDL requires additional stages be added to the pump. The pump head for a two stage pump is double that of the single stage and the KW is linearly related to the number of stages. This conclusion assumes that the same pump characteristic for the single stage is used as stages are added. This is often the case where the discharge is used to select the pump.

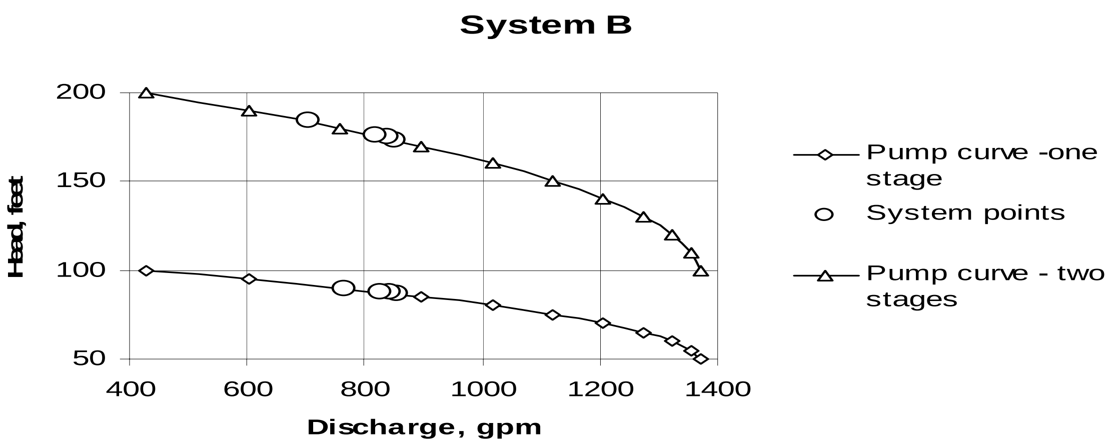

Figure 4. System B operating with single and two stage pump shown with simulated system points.

Table 6. Simulated operating characteristics for System B with a single and two stage pump.

	One stage pump				Two stage pump			
TDL, feet	0	20	40	50	90	110	130	150
Discharge,gpm	855.1	841.8	827.1	767.7	853	840	816.9	704.5
Pivot Pressure, psi	33.9	25.5	17.2	13.7	32.5	24.4	16.3	11.1
Irrigation depth, in.	0.6	0.6	0.6	0.6	0.6	0.6	0.59	0.51
Big gun, gpm	134	121	106	103	132	119	105	100
Head/stage, feet	86.7	87.3	88.1	90	86.7	87.4	88	92
KW	20.0	19.8	19.6	18.6	39.8	39.5	38.7	34.9

Another observation that can be illustrated with this system is the effect of pressure regulators. Figure 5 shows the center pivot hydraulic characteristics for System B assuming there are no pressure regulators with the same sprinkler package. Different pivot pressures were used to simulate the four points on the curve. The regulated system point (Fig. 5) has the same discharge as the first point on the curve. This emphasizes the influence of pressure regulators on a system. Regulators control the nozzle pressure for all heads when the pressure exceeds the regulator pressure along the lateral. The pivot pressure for the unregulated system is one-half that of the regulated system and the application depth decreases with distance from the pivot. The effect of drawdown on a regulated system is best observed by decreased pivot pressure as TDL increases. Systems with big guns are affected by a decrease in discharge as TDL increases. The big gun discharge decreased approximately 10% when the TDL increased 50-60 feet.

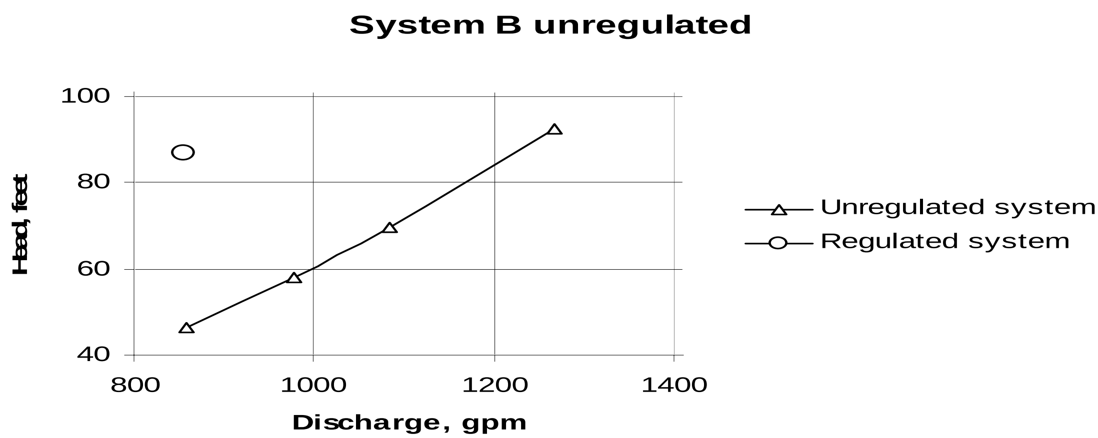

Figure 5. System B center pivot system hydraulic demand curve operating without pressure regulators

System K

System K is an illustration with a much longer lateral length (2584 feet) than previous systems. The topography change is about 3 feet along the entire lateral. Three and four stage pumps were used for the simulations comparing TDL's of 78 and 128 feet. Figure 6 shows the three and four stage pump curves and the simulated operating points. The discharges are almost double from the previous systems to irrigate the larger area. The operating characteristics are show in Table 7. The pivot pressure for the three stage pump and a TDL=128 feet is below that required for the lateral pressure to exceed the pressure regulator settings. The average irrigation depth is reduced by 8%. Figure 7 shows the application depths for each of the simulations. The depth is the same for all simulations to the 1600 feet from the pivot. The reduction in depth results from the smaller depths from this point on to the end of the pivot lateral. The system is not meeting the design but would be difficult to evaluate with catch cans. The application depth is 13% less at the outer end of the system. The best procedure for monitoring systems would be to measure the pivot pressure and compare to minimum pressure required at the time of design.

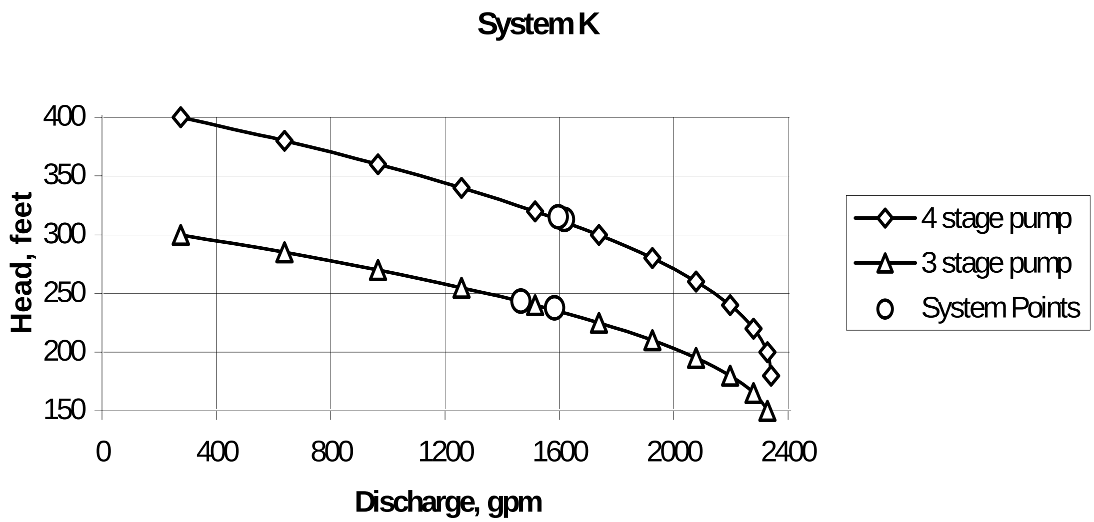

Figure 6. System K operating with three and four stage pumps shown with simulated system points.

Table 7. Simulated operating characteristics for System K with a single and two stage pump.

	four stage pump		three stage pump	
TDL, feet	78	128	78	128
Discharge,gpm	1617	1596	1583	1465
Pivot Pressure, psi	94	73	61	43
Irrigation depth, in.	0.38	0.39	0.39	0.36
Big gun, gpm	156	135	122	105
Head/stage, feet	78.3	78.8	79.3	81.2
KW	136.3	135.4	101.3	96.0

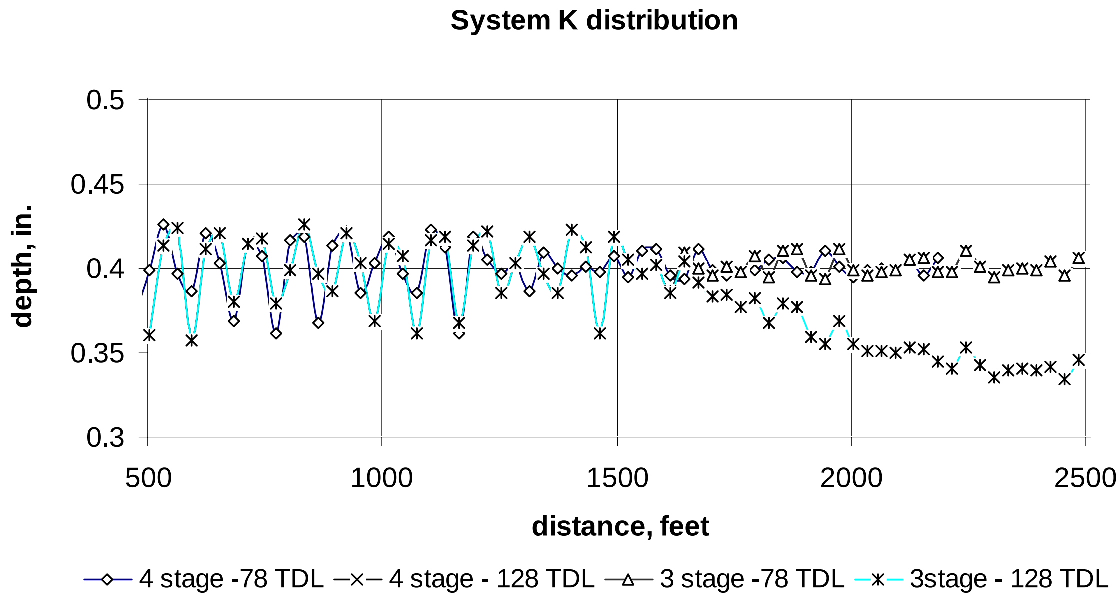

Figure 7. Simulated depths for the System K for the combinations of TDL and pump stages.

SUMMARY

The continual increase in drawdown in the Central Great Plains requires that producers monitor their water table depths and center pivot system operation. The data used for the simulation analysis indicated that many systems are designed to have considerably more pumping capacity than needed. This will automatically provide a factor of safety as the water table drops. The cost of operation of these systems is more expensive since many systems operate with pressure regulators. The excess pressure is dissipated in the regulator before reaching the nozzle and the energy is wasted. It is recommended that each system be analyzed to assure a pumping capacity that meets current needs plus an estimated increase in future water table depths. Monitoring wells in an area provides some guidance for the amount of anticipated increase in TDL requirements.

LITERATURE CITED

McGuire, V.L., 2004, Water-Level Changes in the High Plains Aquifer, Predevelopment to 2003 and 2002 to 2003. Fact Sheet 2004-3097, U.S. Geological Survey.