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Livestock Water Pumping with Wind and Solar Power

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Abstract. *Recent developments in pumping technologies have allowed for efficient use of renewable energies like wind and solar to power new pumps for remote water pumping. A helical type, positive displacement pump was developed a few years ago and recently modified to accept input from a variable power source. This pump was tested at different pumping depths with both solar and wind energy power sources. The solar power source consisted of 640 W of photovoltaic panels and the wind power source was a 1000 W wind turbine. For Bushland, Texas, the solar powered pump provided enough water for the 150 beef cattle in the summer months of June, July, and August and was adequate in winter months when water consumption was lower. The wind powered pumping system provided sufficient water in summer for the same number of cattle (150 head), but had excess water in the winter and spring when winds were higher and water consumption was lower.*

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Keywords. Wind power, water pumping, windmills, solar power, photovoltaic, PV, helical pump, livestock water.

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Introduction

Farmers and ranchers need to water their livestock as reliably and as inexpensively as they can in order to be competitive in the global marketplace. Mechanical windmills with piston pumps have pumped water for livestock very reliably and inexpensively for over a hundred years. However, the cost of mechanical windmills and the maintenance of the piston pump have increased steadily over the past few decades. Testing at the USDA-ARS Conservation and Production Research Laboratory, Bushland, TX, has shown that for a 30 m pumping depth, a 2.44 m diameter small wind turbine on a 20 m guyed pipe tower with a smart controller and a 10-stage centrifugal pump can perform better than a 2.44 m diameter mechanical windmill on a 10 m windmill-type tower with a piston pump (Vick and Clark, 1997). The wind-electric system cost 25% less than the mechanical system. However, it was also shown that a 3 m diameter wind turbine (18.5 m hub height) with a 19-stage centrifugal pump at a 73 m pumping depth could only pump about half as much water as a 3 m diameter mechanical windmill (10 m hub height) with a piston pump during the low wind months of the summer (Vick, 1999).

For the past fifteen years, solar-PV (photo-voltaic) water pumping systems have been installed with either diaphragm, centrifugal, or piston pumps. The diaphragm pumps have been used successfully for small daily water volumes and shallow pumping depths (500 to 1,500 liters/day and 5 to 30 meter pumping depths). The centrifugal pumps have been used for larger daily water volumes and moderate pumping depths (2,000 to 10,000 liters/day and 5 to 75 meter pumping depths). Lastly, the piston pumps (with a pump jack) have been used to pump water for small to moderate daily water volumes and deep pumping depths (500 to 5,000 liters/day and 100 to 300 meter pumping depths). For daily water volumes of 5,000 to 10,000 liters/day at pumping depths in the 50 to 100 meter range, there really has not been a good reliable, economical solar-PV system for pumping water.

Recently Grundfos[1] designed a helical pumping system which could be powered by either solar-PV power or wind power. A helical pump (a positive displacement pump) should have higher flow rates at deeper pumping depths with lower power requirements than a centrifugal pump (a high volume pump). A Grundfos helical pump was selected and data were collected at 50, 75, and 100 m pumping depths. Two identical pumps were purchased with one powered by a 1000 W wind turbine and the other one by a 640 W solar-PV array.

Wind Turbine Description and Testing

The 1000 W wind turbine was installed on a 19.2 m (63 ft) tilt-up guyed pipe tower and instrumentation were installed to measure wind turbine performance on an adjacent tower. The wind speed was measured by an anemometer mounted at hub-height of the wind turbine. Wind direction was measured on a nearby tower. The wind turbine produced variable voltage/variable frequency 3-phase AC electricity which was rectified to DC in a control system supplied by the pump manufacturer before it was connected to the helical pump motor. An internal controller imbedded in the submersible helical pump motor determined if input power was sufficient to pump water and determine if the well water level was too low to pump water. The power to the motor from the wind turbine could also be controlled manually by an above ground level controller.

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[1] The mention of trade or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agricultural.

Figure 1. The 1000 W wind turbine installed on a 19.2 m tilt-up guyed pipe tower (Bushland, TX).

Parameters measured included AC electrical power, AC voltage, and electrical frequency produced by the wind turbine; DC voltage and DC current measured between the controller and the helical pump motor, water flow rate and water pressure. From the electrical frequency, the blade rotor speed could be determined. All data related to the wind-powered water pumping system were sampled every second by a data logger and one-minute averages were stored on a storage module. These data were downloaded to a personal computer (PC) on a weekly basis and then processed with a Quick Basic® computer program which binned the data into 0.5 m/s wind speed bins. A “Log Book” was kept on the experiment where observations, calibrations, daily water volumes, highest daily wind speed, etc. were recorded.

Solar Array Description and Testing

The solar-photovoltaic (PV) water pumping system we tested was powered by four 160 W/ 24 V multi-crystalline silicon modules which were connected in series to provide 640 W of power. The array was connected to the pump motor through a controller which served as: a junction box between the motor and solar modules, a switch to turn pump on or off, and a display for various error codes if no water pumping occurred. The PV modules were installed on a pole mount in a fixed position (non-tracking). Although the solar modules were in a fixed position, the solar array incidence was changed twice per year at the spring and autumnal equinoxes (45

degree incidence during fall and winter, 25 degree incidence during spring and summer – Bushland latitude is 35.18^{o} North).

Figure 2. Solar panels used for livestock water pumping at Bushland, TX.

Parameters measured included solar irradiance, PV module temperature, DC voltage and DC current between the solar array and the pump motor, water flow, and water pressure. The irradiance was measured with a pyranometer mounted in the plane of the PV modules and a thermocouple was mounted to the back of one of the solar-PV modules to measure the solar module temperature. In addition, a flow meter for measuring the water flow rate and a pressure transducer for measuring the water pressure were included in the test arrangement. All the measured data were sampled every second and averages recorded every minute on a data logger. The data were downloaded from the storage module once a week and transferred to a PC. A Quick Basic® computer program was written to bin the data in 100 W/m^2 irradiance bins and could display graphs of the measured data versus irradiance. This computer program helped in determining if problems existed with the instrumentation or pumping performance. Also, a “Log Book” was kept on the experiment where observations, calibrations, daily water volumes, flow rates, etc. were recorded.

Results

The pumps were tested over a period of about two years. The wind speed data bins between 4 and 10 m/s contained at least 500 one-minute averages and the solar irradiance data bins between 200 and 1000 W/sq m also contained at least 500 one-minute averages.

Wind Pumping Results

Figure 3 contains the water flow rate data for the three pumping depths when powered by the wind turbine. Notice that the water flow began at between 4 and 5 m/s for all three pumping depths. The flow rate increased rapidly until the maximum pumping rate was obtained for each depth. Maximum flow rates varied from 17 l/min for the 100 m depth to 19.5 l/min for the 50 m depth. Maximum flow rates remained constant for all pumping depths after wind speed reached 10 m/s except for the 100 m depth. Data beyond 14 m/s contained some records when the wind turbine furled (e.g. wind turbine turned out of the wind due to rotor axis offset from tower centerline), so some decreases in flow was observed.

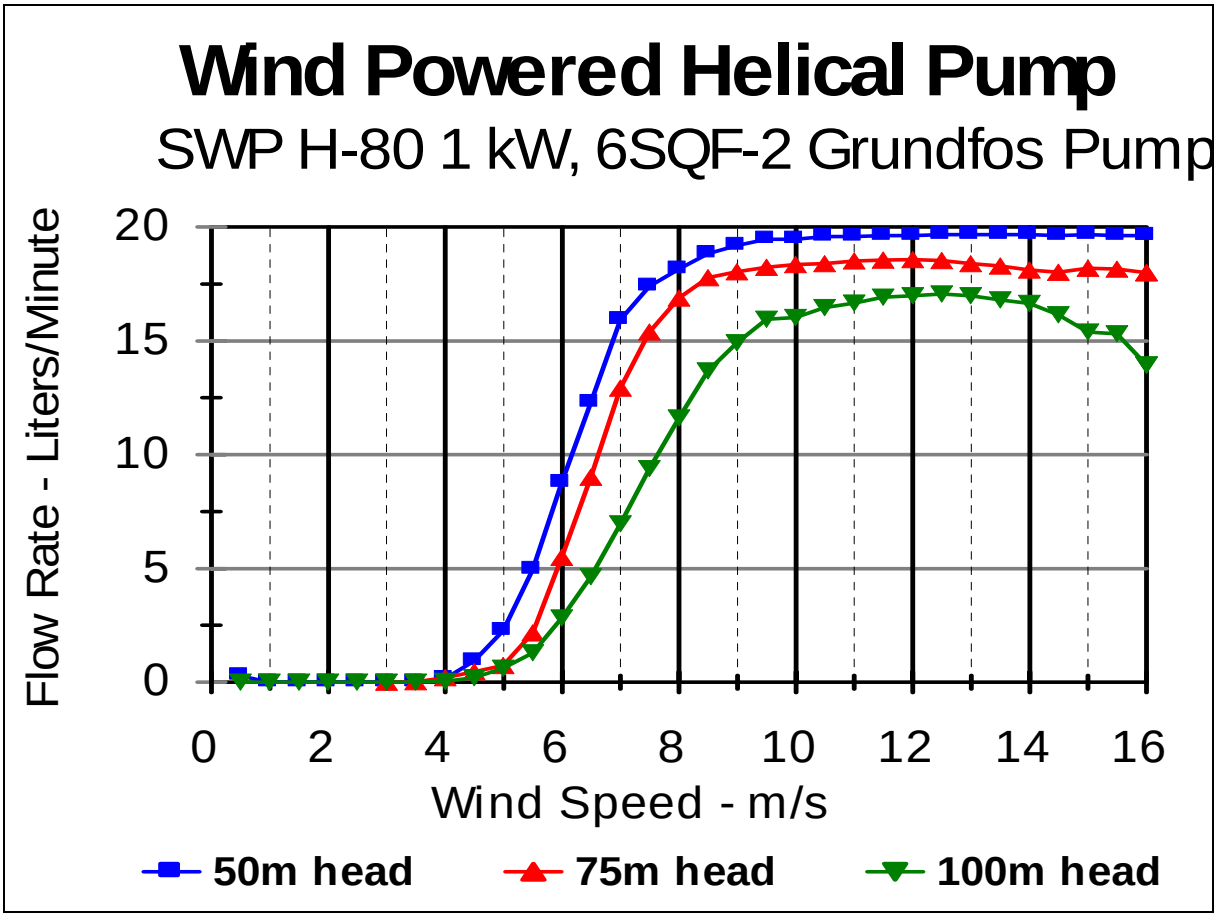

Figure 3. Measured flow rates at three pumping depths for helical pump when powered by a 1000 W wind turbine.

Selecting the 75 m pumping depth, the efficiencies of the different components of the pumping system were evaluated as shown in Figure 4. The helical pump and motor efficiency were determined together and found to be higher than centrifugal pump-motor combinations when operated over a range of speeds. (Clark, 1994) The pump-motor efficiency was about 55% for

wind speeds above 8 m/s. The wind turbine efficiency was lower than a typical small wind turbine operated at variable speed (Vick, 1998). This lower wind turbine efficiency can be attributed to the wind turbine not being sufficiently loaded in this application (Neal, 2007).

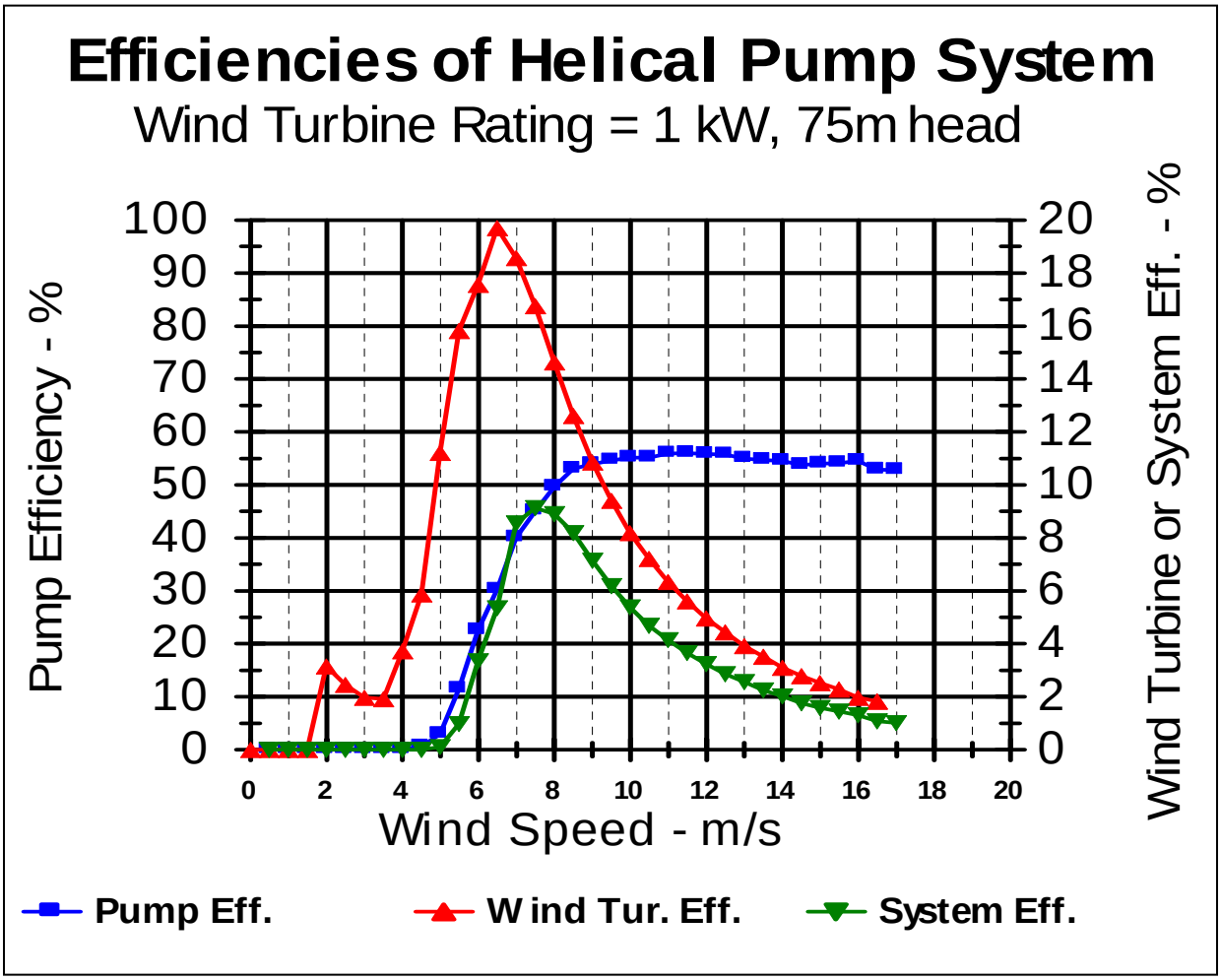

Figure 4. Efficiencies of the various components of a wind-powered water pumping system using a helical pump.

The overall system efficiency peaked at about 9% after following the pump efficiency curve until the wind turbine reached its peak efficiency, and then the system efficiency followed the wind turbine efficiency curve. These same shaped efficiency curves have been observed for other small stand alone wind powered pumping systems.

The flow rate curves were combined with monthly wind speed histograms to calculate an average daily water volume for each month. These data are shown in Figure 5. As expected, the total water pumped at 50 m depth is significantly higher than either 75 or 100 m depths. The daily average volume for the 50 m depth was well over 10,000 l/min with only August being less than 10,000 l/min. The daily average volume for the 100 m depth was slightly above 5,000 l/min, with August again being the only month to drop below 5,000 l/min.

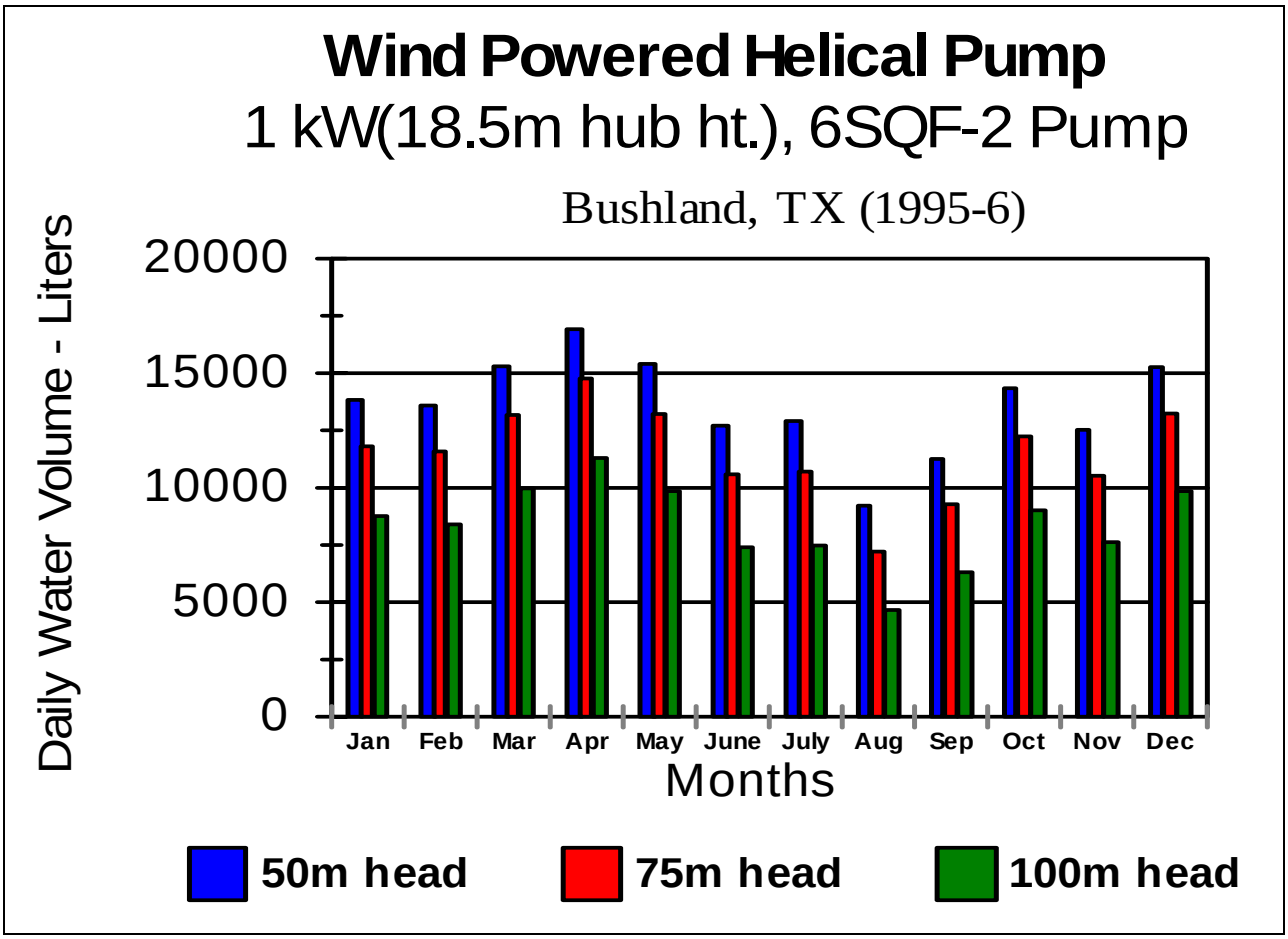

Figure 5. Estimated water pumped per day for each month for the three pumping depths using the 1000 W wind turbine and helical pump.

Solar Pumping Results

Water began flowing at a solar irradiance of 100 W/sq m and continued to increase until it reached a maximum at 600 to 1000 W/sq m depending on pumping depth (Figure 6). After a maximum flow rate was reached, the flow rate remained constant to 1400 W/sq m. Maximum pumping rates ranged from 17 l/min for the 100 m depth to 19 l/min for the 50 m depth; slightly less than for wind powered pumping system with the same pump. These flow rates were almost identical to the one for wind powered pumping indicating that these pumps operated almost the same with either power source.

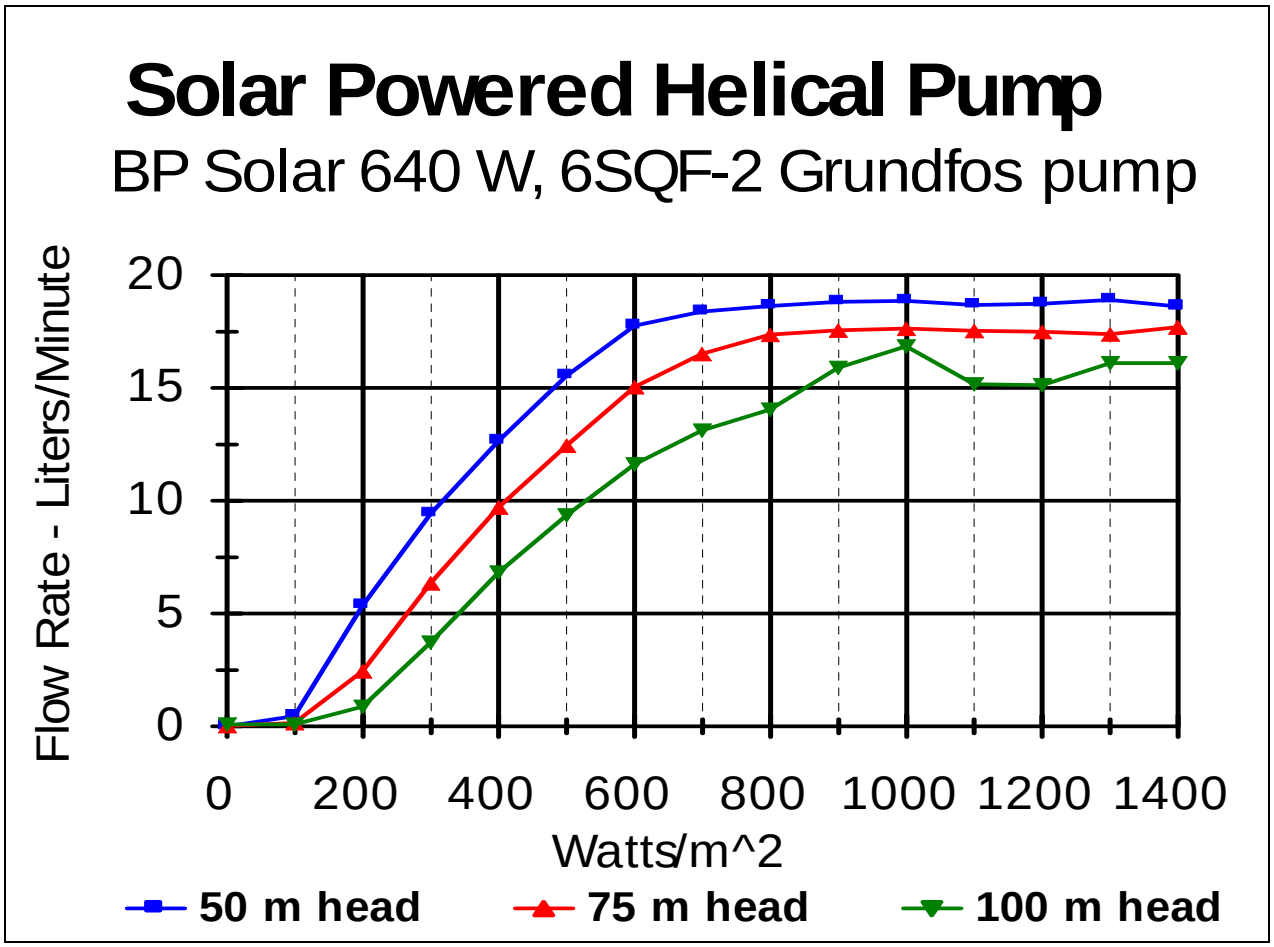

Figure 6. Measured flow rates at three pumping depths for helical pump when powered by a 640 solar photovoltaic array.

The efficiency of the pump and motor using solar power were almost identical to the efficiency when using wind power leveling out at 55% (Figure 7). The efficiency of the solar panels was fairly typical of solar panels and peaked at about 13% and dropped off to about 8% at an irradiance of 1000 W/ sq m. Overall system efficiency of the solar powered pump was much like the system efficiency for the wind powered pump in that the curve followed the pump efficiency curve until a peak pump efficiency was measured and then it followed the solar panel efficiency line. The peak system efficiency was only 6.7% for the solar powered pump compared to a 9% peak system efficiency achieved with the wind powered pump.

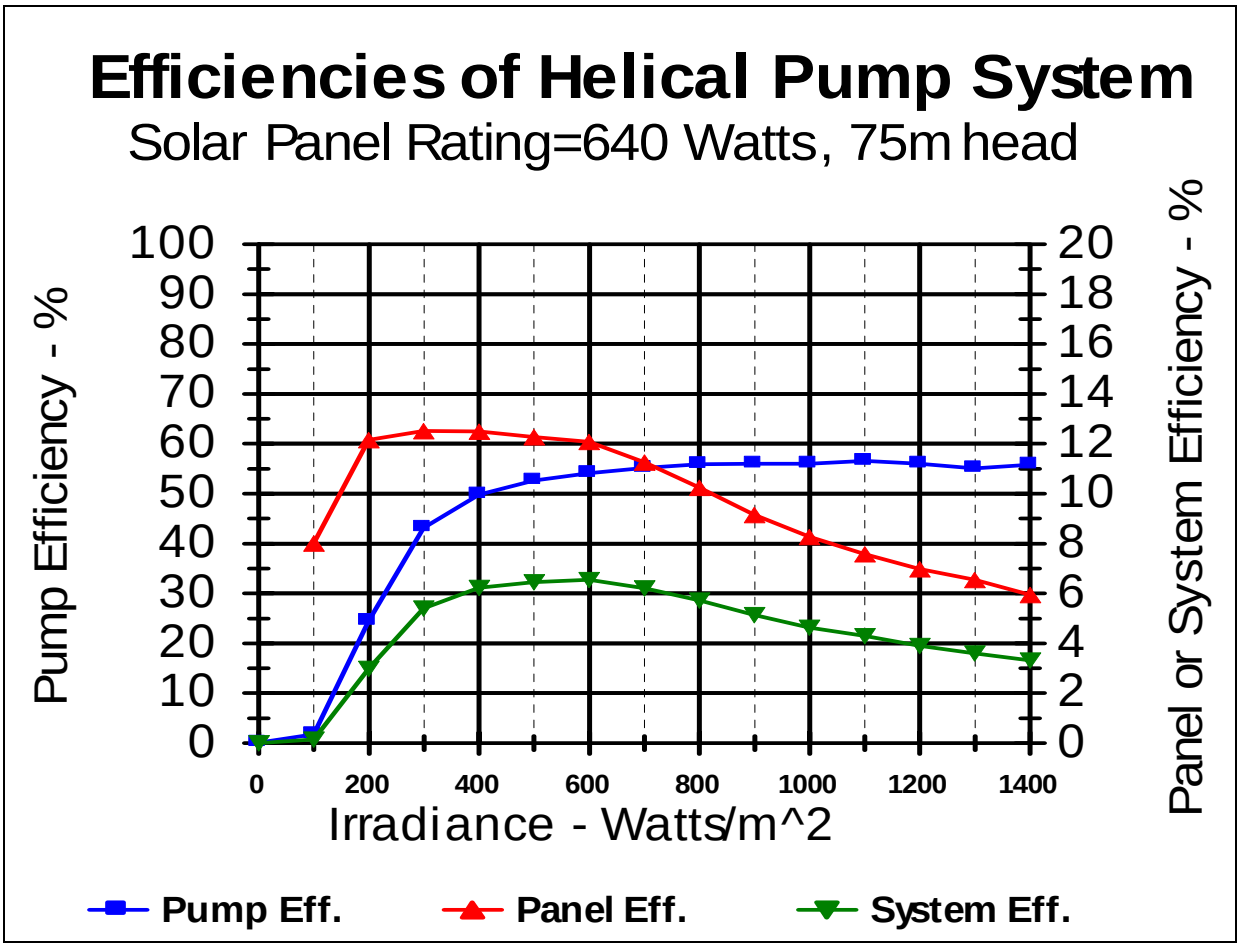

Figure 7. Efficiencies of the various components of a solar powered water pumping system using a helical pump.

Again using the flow rate curves for the solar powered water pump and the monthly solar irradiance histograms, a daily average volume of water pumped in each month was determined. These daily volumes showed less variation from month to month with the summer months pumping more water than the winter months (Figure 8). The volumes at the 100 m depth had little variation from month to month and averaged about 6,000 l/day.

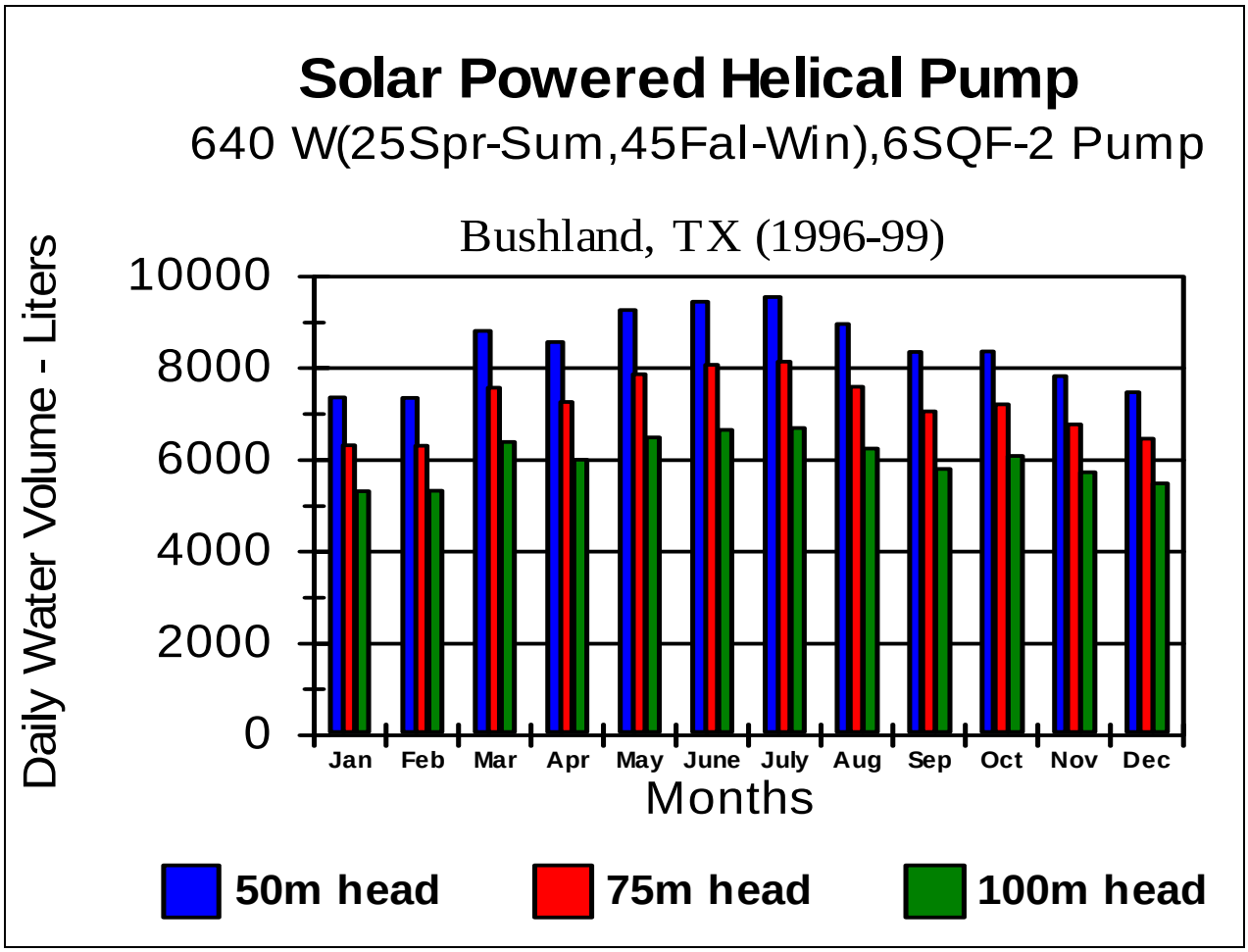

Figure 8. Estimated water pumped per day for each month for the three pumping depths using the 640 W solar photovoltaic array and helical pump.

Comparison of Systems

Figures 9, 10, and 11 show the comparison of the wind and solar powered pumping systems for each pumping depth. Here it is easy to see the monthly differences in the daily water pumped for each of the systems. The wind powered system out performed the solar powered system in all months except for the month of August. The reason for this phenomenon is that in most months, the wind provides more power than is needed to pump the water from either the 50, 75, or 100 m pumping depths. A much more efficient water storage system can be designed for the solar powered pump because it has less variation from day to day than the wind system. The storage system does not have to be over sized to take care of high volumes pumped from October to May since cattle normally do not drink as much water in the cooler months as in the summer months.

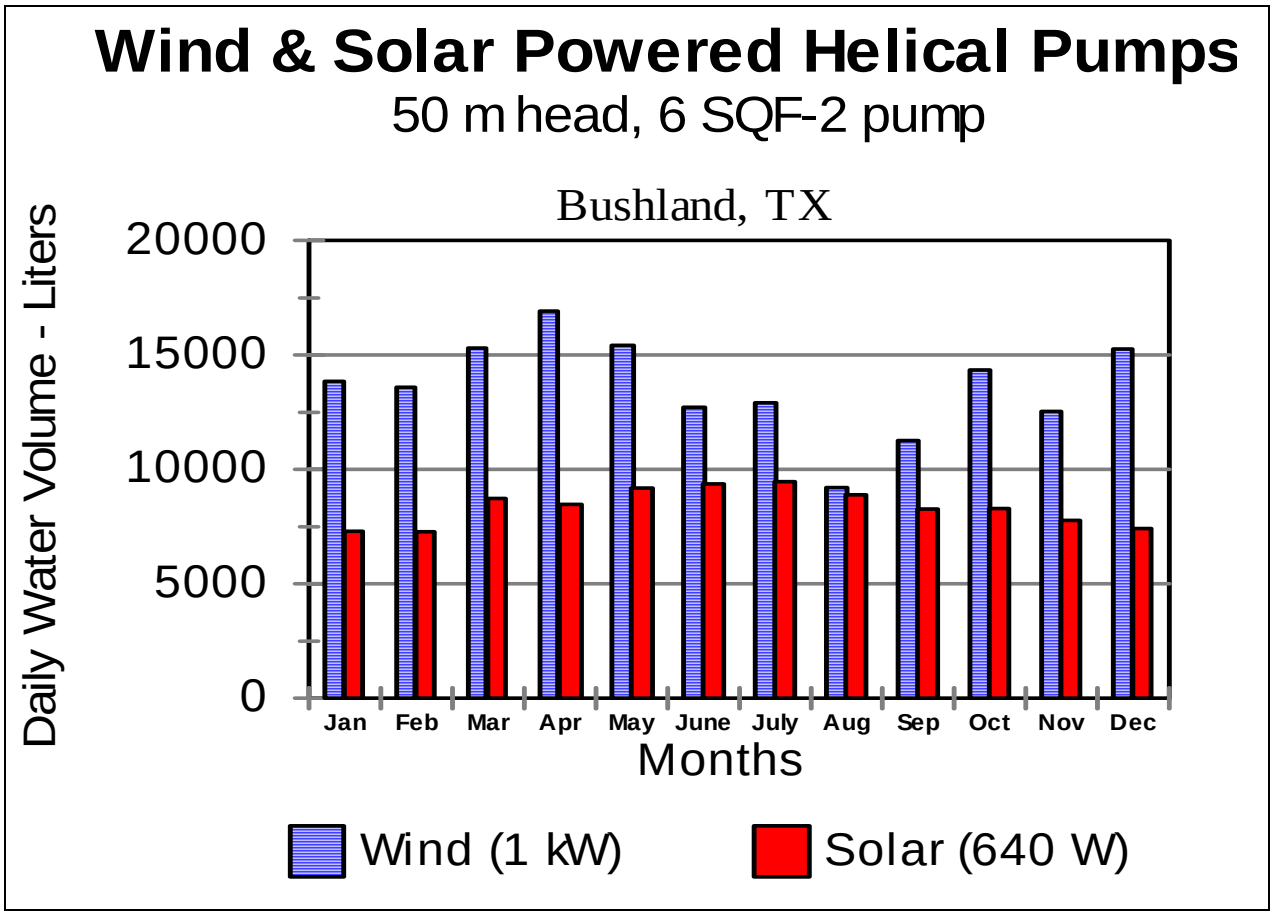

Figure 9. Daily comparisons of wind and solar powered water pumped at the 50 m pumping depth. Minimum volume is approximately 7,000 liters per day.

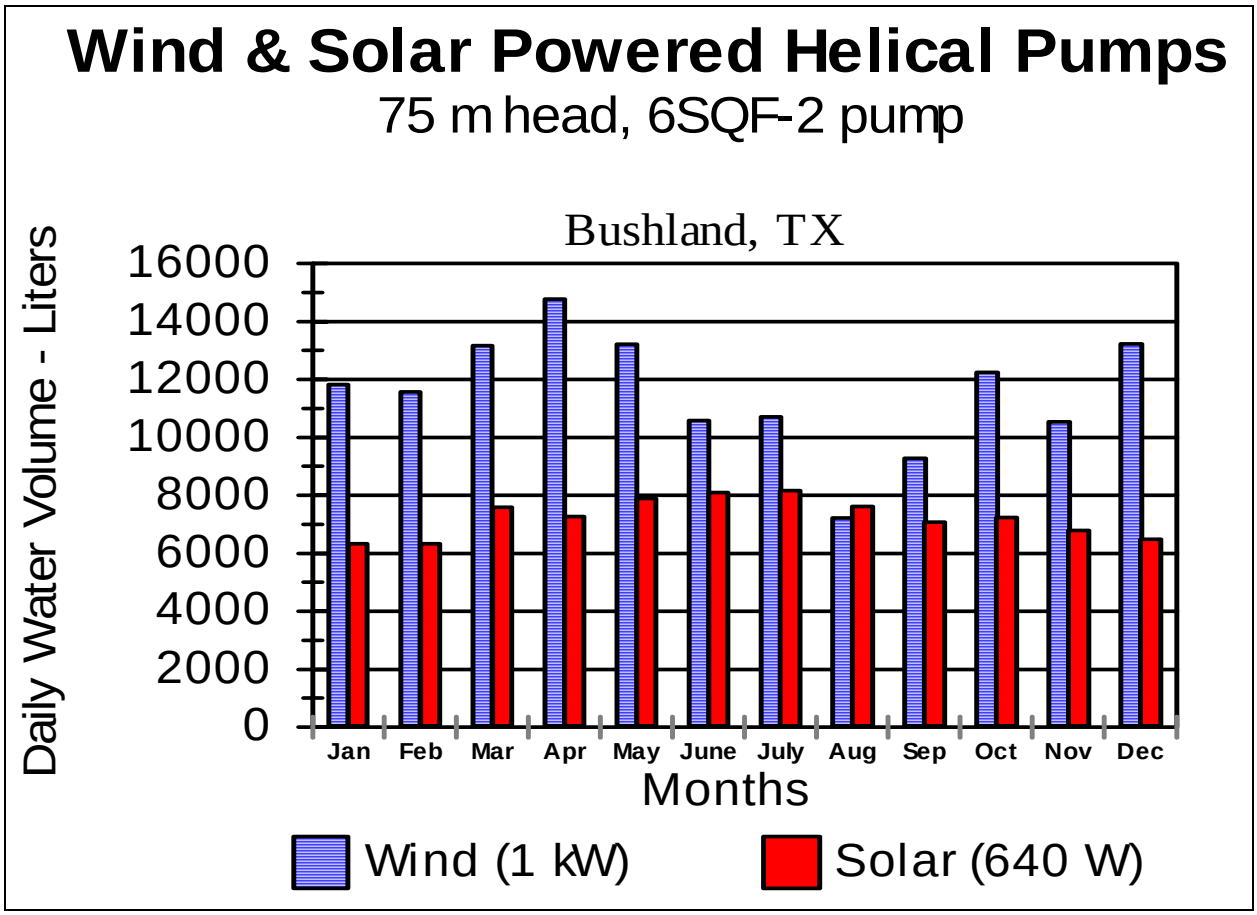

Figure 10. Daily comparisons of wind and solar powered water pumped at the 75 m pumping depth. Minimum volume is approximately 6,200 liters per day.

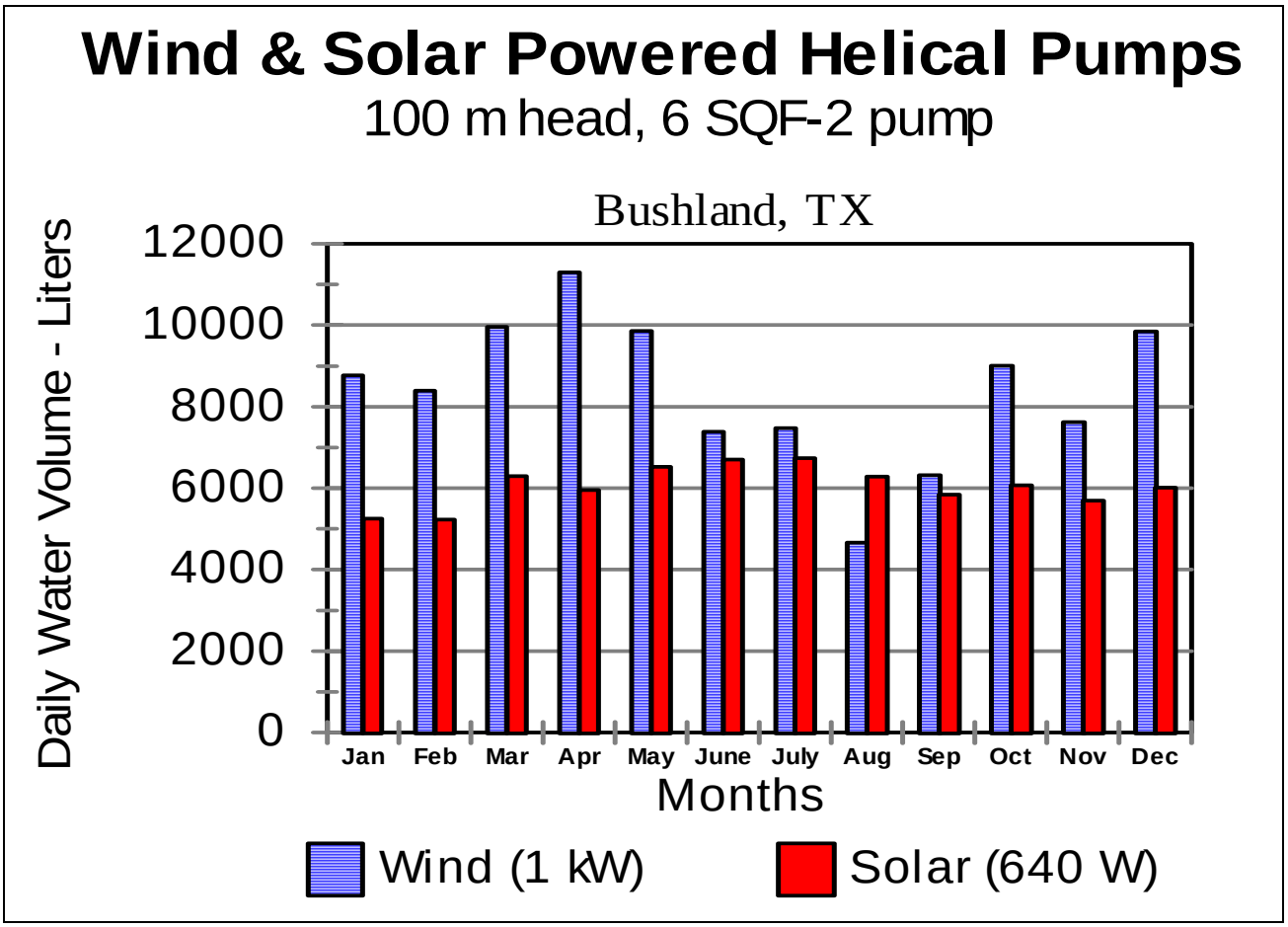

Figure 11. Daily comparisons of wind and solar powered water pumped at the 100 m pumping depth. Minimum volume is approximately 4,800 liters per day.

Conclusions

Two identical helical submersible water pumps were tested using different power sources. The pumps were tested at three pumping depths typical of pumping depths in the Southern Great Plains: 50, 75, and 100 m. A 1000 W wind turbine which produced 3-phase electricity and a 640 W solar-PV array were used as power sources. The systems were compared using the daily water volume pumped for each month and evaluated by comparing the volume of water needed by the livestock in each month. Both systems provided sufficient water for approximately 150 head of cattle in all months. However, the solar system provided a more uniform volume of water over the entire year with slightly more water in summer months than in winter months. This matches animal water use very well because beef cattle consume more water during the hotter summer months. The wind system had difficulty meeting the water requirements in August when winds are low throughout most of the Southern Great Plains. The wind system also pumped much more water than needed in winter and spring months creating a need for an extra large storage tank or created a wasteful condition of pumping unused water, thus requiring more management by the farmer or rancher. The solar-photovoltaic helical pumping system appears to provide adequate water for all months and allows for an efficient storage system to be incorporated with this pumping system in the Southern Great Plains.

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